Cam morphology of femoroacetabular impingement syndrome

– Clinical, radiological and follow-up studies

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“Don’t think about doing. Do, and be done with it”

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CONTENTS

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ABSTRACT

Femoroacetabular impingement syndrome (FAIS) leads to hip pain and reduced hip function in young athletes. Recent studies have reported high-impact sporting activities during adolescent growth as an important cause of cam morphology. However, not all athletes with cam morphology develop symptoms and dysfunction related to FAIS, nor do they require surgical treatment. The question of why some athletes with cam morphology function well at a high level of sports for years, while others do not, and possible differences between genders and different sports, remains to be answered.

The aim of this thesis is to investigate the correlation between cam morphology, hip- joint range of motion (ROM) and hip pain in young elite athletes and patient-reported outcome measures (PROMs) and the rate of athletes still active at elite level after arthroscopic treatment for FAIS, and to make comparisons between genders, sports types and evaluations over time.

Study I is a cross-sectional study comprising young athletes (60 male football players, 40 male and 35 female skiers). The prevalence of cam morphology, hip ROM, hip pain and FAIS is studied. Football players had reduced hip rotation compared with skiers, independent of cam morphology and hip pain. Skiers had a higher proportion fulfilling the diagnostic criteria for FAIS.

Study II is a cohort study comparing hip ROM over 2 years in young skiers (n=30) with and without cam morphology. All the skiers reduced their hip rotation, independent of cam morphology. A statistical, not clinically relevant, larger reduction was shown in internal rotation in skiers with cam morphology.

Study III is a cohort study investigating the correlation between cam morphology, activity level and hip pain over 5 years in young skiers (n=60). Activity level and cam morphology had no, or only a low, correlation with hip pain.

Study IV is a cross-sectional study comprising 919 athletes undergoing hip arthroscopy for FAIS. Preoperative PROMs and types of sport participation between genders is studied. Females had a longer symptom duration and more self-reported dysfunction. Females were equally active in horseback riding and football, while almost the majority of males were active in football.

Study V is a cohort study comprising 551 athletes undergoing arthroscopic treatment for FAIS. The rate of continued sporting activity is evaluated and compared between sports, genders and PROMs. Only 25% were still active at pre-injury level after 2 years, with no gender difference, but with a greater improvement in PROMs.

Keywords: femoroacetabular impingement syndrome, cam morphology, athletes, sports medicine, adolescent, return to sport, hip arthroscopy, patient reported outcome measures

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SAMMANFATTNING PÅ SVENSKA

Femoroacetabulärt impingement syndrom (FAIS) är en orsak till höftsmärta och nedsatt höftfunktion hos unga idrottare. Studier har rapporterat att hög-belastande idrottsaktiviteter under tonårens tillväxtperiod är en orsak till cam morfologi (cam). Emellertid utvecklar inte alla idrottare med cam symptom och nedsatt funktion relaterade till FAIS, eller behöver kirurgisk behandling för detta. Frågor kvarstår varför vissa idrottare med cam kan fortsätta på en hög idrottsnivå under flera år medan andra inte gör det, och hur detta skiljer mellan kön och olika idrotter.

Målet med denna avhandling är att undersöka korrelationen mellan cam, höftledsrörlighet (ROM) och höftsmärta hos unga elitidrottare, samt patientrapporterade utfallsmått (PROMs) och andelen som fortsatt är elitaktiva efter artroskopisk behandling för FAIS, och jämföra mellan kön, idrotter och förändring över tid.

Studie I är en tvärsnittsstudie inkluderat unga elitidrottare (60 manliga fotbollsspelare, 40 manliga och 35 kvinnliga skidåkare). Prevalens av cam, höft ROM, höftsmärta och FAIS undersöks. Fotbollsspelarna hade nedsatt höftrotation jämfört med skidåkarna, oavsett cam eller höftsmärta. Högre andel av skidåkarna (både män och kvinnor) up- pfyllde de diagnostiska kriterier för FAIS jämfört med fotbollsspelarna.

Studie II är en kohortstudie som jämför höft ROM under 2 år hos unga elitskidåkare (n=30) med och utan cam. Alla skidåkare minskade sin höftrotation oavsett cam. En statistisk, men ej klinisk relevant, mer uttalad minskning i inåtrotation fanns hos skidåkare med cam.

Studie III är en kohortstudie som undersöker korrelation mellan cam, aktivitetsnivå och höftsmärta hos 60 unga skidåkare under 5 år. Ingen eller endast låg korrelation fanns mellan aktivitetsnivå, cam och höftsmärta efter 5 år.

Studie IV är en tvärsnittsstudie med 919 idrottare som genomgått artroskopisk behandling för FAIS. Preoperativa PROMs och idrottstyper mellan kön undersöks. Kvinnor hade längre duration och högre grad av symtom. Ridning och fotboll var lika vanligt hos kvinnor medan fotboll dominerade hos män.

Studie V är en kohortstudie med 551 idrottare som genomgått artroskopisk behandling för FAIS. Andelen som är på samma nivå av idrott undersöks och jämförs mellan idrot- ter, kön och PROMs. Endast 25% var fortfarande på samma nivå av idrott efter 2 år, utan någon könsskillnad, men med en större förbättring i PROMs.

Nyckelord: femoroacetabulärt impingement syndrom, cam morfologi, idrottare, idrottsmedicin, tonåringar, återgång till idrott, höftartroskopi, patient rapporterade utfallsmått.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals

I. Swärd Aminoff A, Abrahamson J, Todd C, Thoreson O, Agnvall C, Laxdal G, Pruna R, Jónasson P, Swärd L, Karlsson J, Baranto A. (2020). **Differences in cam morphology and hip range of motion between young skiers and soccer players.**
[Submitted]

II. Abrahamson J, Swärd Aminoff A, Todd C, Agnvall C, Thoreson O, Jónasson P, Karlsson J, Baranto A. (2018). **Adolescent elite skiers with and without cam morphology did change their hip joint range of motion with 2 years follow-up.**
Knee Surg Sports Traumatol Arthrosc: 27(10): 3149-3157

III. Abrahamson J, Jónasson P, Swärd Aminoff A, Sansone M, Todd C, Karlsson J, Baranto A. (2020). **Hip pain and its correlation with cam morphology in young skiers - a minimum of 5 years follow-up.**
J Orthop Surg Res: 15, 444. doi: https://doi.org/10.1186/s13018-020-01952-8

IV. Abrahamson J, Lindman I, Sansone M, Öhlin A, Jónasson P, Karlsson J, Baranto A. (2020). **Female athletes have more and longer duration of symptoms prior to arthroscopy for femoroacetabular impingement syndrome.**
[Submitted]

V. Abrahamson J, Lindman I, Sansone M, Öhlin A, Jónasson P, Karlsson J, Baranto A. (2020). **Low rate of high-level athletes maintained a return to pre-injury sports two years after arthroscopic treatment for femoroacetabular impingement syndrome.**
J Exp Orthop: 7(1): 1-8. doi: https://doi.org/10.1186/s40634-020-00263-5

ADDITIONAL PUBLICATIONS BY THE AUTHOR ON THE SAME TOPIC

Todd C, Witwit WA, Abrahamson J, Sward A, Karlsson J, Baranto A, Jónasson P.
A low pelvic incidence angle may not place young athletes at risk of developing cam morphological changes in the hip joint.
J J Sports Med. 2018: 5(3).

ABBREVIATIONS

α	alpha
AAOS	The American Academy of Orthopaedic Surgery
ADL	Activity of Daily Living
AOSSM	American Orthopaedic Society for Sports Medicine
AP	Anterior-Posterior (pelvic view radiography)
BMI	Body Mass Index
CT	Computed Tomography
DG	Digital Goniometer
ER	External Rotation
FABER	Flexion ABduction External Rotation test
FADIR	Flexion ADduction Internal Rotation test
FAIS	FemoroAcetabular Impingement Syndrome
HAGOS	Copenhagen Hip And Groin Outcome Score
HSAS	Hip Sports Activity Scale
iHOT	international Hip Outcome Tool
ICC	Interclass Correlation Coefficient
IQR	InterQuartile Range
IR	Internal Rotation
IR^{sit}	Internal Rotation in sitting position
MIC	Minimal Important Change
MRI	Magnetic Resonance Imaging
NSAID	Non-Steroidal Anti-Inflammatory Drugs
OA	OsteoArthritis
PA	Physical Activity
PASS	Patient Acceptable Symptomatic State
PROM	Patient Reported Outcome Measure
QoL	Quality of Life
ROM	Range Of Motion
r_s	Spearman's rank-order correlation test
RTS	Return To Sport
RTS^{pre}	Return To pre-injury Sporting level
SCFE	Slipped Capital Femoral Epiphysis
SD	Standard Deviation
THA	Total Hip Arthroplasty
UG	Universal Goniometer
VAS	Visual Analogue Scale

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BRIEF DEFINITIONS

α-angle: expresses and quantifies the presence and size of cam morphology.

Cam morphology: non-spherical femoral head, located at the femoral head-neck junction.

Cohort study: a study design that follows a group of subjects over time.

Cross-sectional study: a study design that investigates a study population at one particular time.

Femoroacetabular impingement syndrome: the diagnosis set when all the criteria for radiological cam and/or pincer morphology, hip pain and reduced hip range of motion and/or a positive impingement test are fulfilled.

Incidence: the proportion of new cases of a given injury/disease during a given time in a defined population.

Mixed impingement: cam and pincer morphologies are present together.

Pincer morphology: a local or global over-coverage of the femoral head by the acetabular rim.

Prevalence: the total proportion/number of a given injury/disease during a given time in a defined population.

Range of motion: the measured distance and direction, often in degrees, to which a joint can be extended.

Reliability: the overall consistency of a measurement and the degree to which it is free from measurement errors.

Return to sports: the athletes' ability to return to his/her preferable sport.

Validity: the degree to which a measurement is likely to correspond accurately to the real world.

1

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INTRODUCTION

1.1 HISTORY

During the last few decades, femoroacetabular impingement syndrome (FAIS) has attracted increased attention as a cause of hip pain and symptoms in young athletes[1,2]. Back in 1936, Smith-Pedersen reported the idea of an impingement occurring through movements of the hip joint, resulting in a bone-on-bone contact that may cause hip pain, reduced range of motion (ROM) and reduced function in the hip[3]. Later, a non-spherical-shaped femoral head, described as 'tilt deformity' by Murray in 1965[4] and 'pistol grip deformity' by Stulberg in 1975[5] (today known as cam morphology), was repeatedly hypothesized as a cause of hip osteoarthritis (OA). Not until several years later, in the early 1920s, did Ganz and colleagues present the formal concept of FAI[1]. Since then, FAI has attracted large-scale scientific interest and, in the Warwick Agreement on femoroacetabular impingement syndrome, it was stated that FAI is a syn- drome that consists of not only morphological changes, but also symptoms and clinical features of the hip joint[2]. The FAI syndrome or FAIS is the main topic of this thesis.

1.2 HIP ANATOMY AND BIOMECHANICS

1.2.1NORMAL

The hip joint consists of the femoral head and acetabulum at the pelvis, and can be described as a ball-and-socket joint that allows a wide ROM in all three planes. The articular surfaces of the femoral head and acetabulum is covered by a layer of hyaline cartilage. This layer is shock absorbent and enables smooth movements in the hip joint. The labrum is a ring of fibrocartilage that partly surrounds and deepens an otherwise relatively shallow acetabulum, supporting its stability, and also functioning as a shock absorber, distributing pressure and joint fluid and giving lubrication to the joint (Figure 1)[6,7]. Free nerve endings and sensory end organs are located in the labrum, which may contribute to nociceptive and proprioceptive functions[8]. The stability of the hip joint is further enhanced by the joint capsule, reinforced by three strong ligaments: anteriorly, the iliofemoral ligament, which prevents excessive extension, antero-inferiorly, the pubofemoral ligament, which prevents excessive abduction and limits extension, and, posteriorly, the ischiofemoral ligament, which helps to stabilize the hip in extension (Figure 1). All three ligaments also limit internal rotation (IR). The ligamentum teres is the only intra-articular connection between the femur and the pelvis. It runs from the ace- tabular fossa (the non-articular part of the acetabulum) and inserts at the fovea capitis (femoral head), thereby acting as an intrinsic stabilizer of the hip[9].

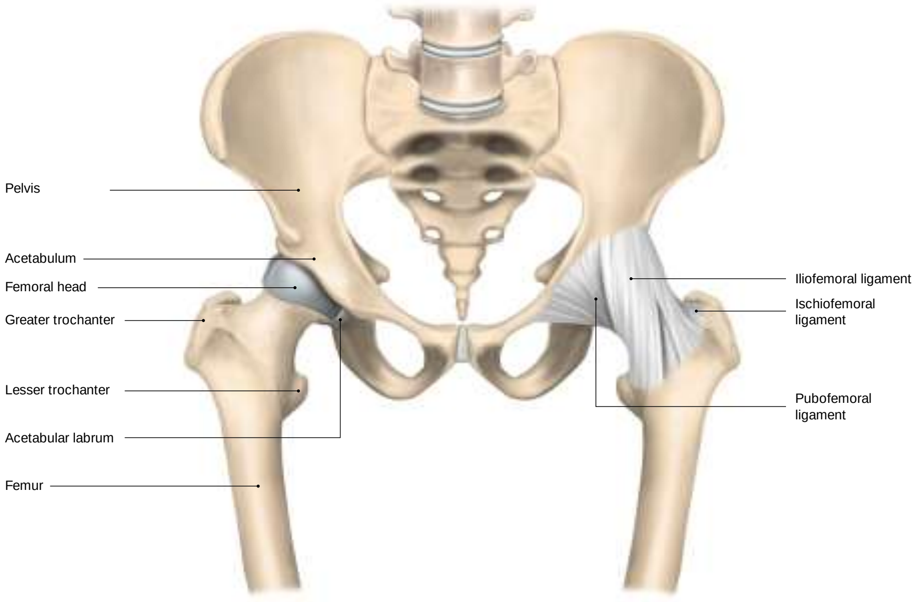

Figure 1. Frontal view of the hip joint and pelvis and the left hip showing the ligaments.

The large number of muscles that are attached around the hip joint participate in the stabilization of the joint and are the main point for movements, control and balance of the lower extremities and the spine. They can be divided into four groups of muscles related to their location around the hip joint, contributing to movements in all three planes; sagittal (flexion/extension), frontal (abduction/adduction) and transversal (internal/external rotation) (Figures 2-3).

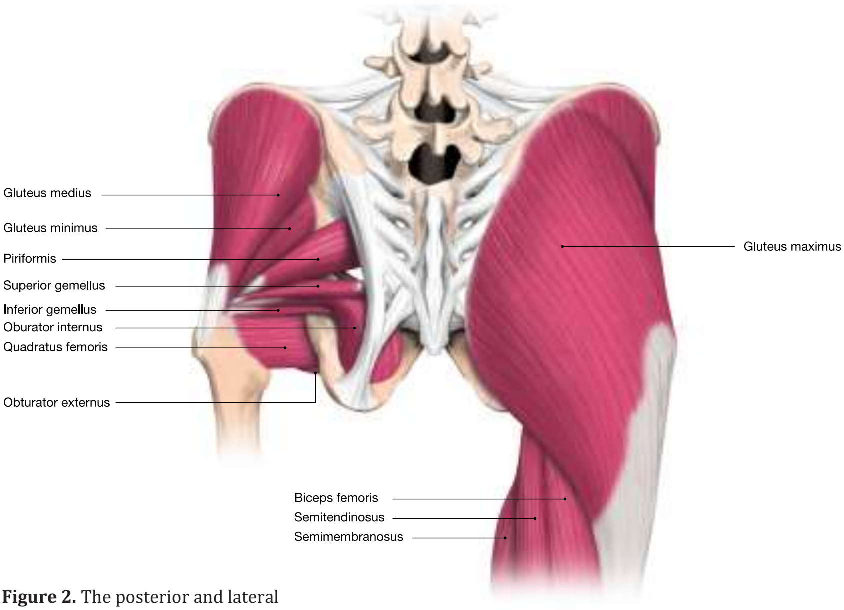

Figure 2. The posterior and lateral muscle groups of the hip. The main function of the posterior muscles is hip external rotation (left hip) and extension (right hip). The main function of the lateral muscles (i.e. the gluteus medius and minimus seen in the left hip) is hip abduction and internal rotation.

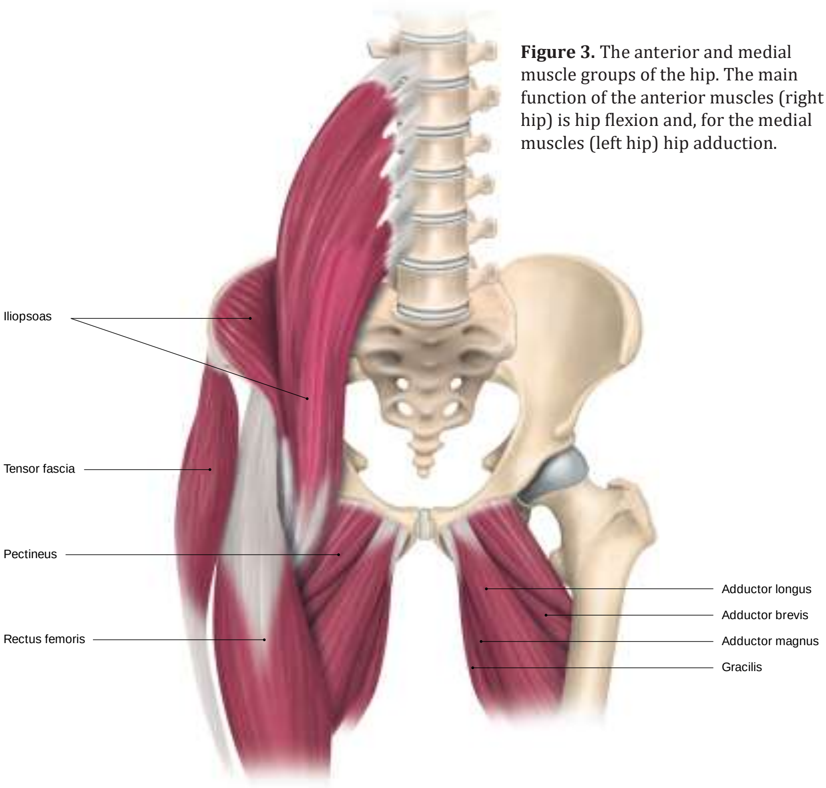

Figure 3. The anterior and medial muscle groups of the hip. The main function of the anterior muscles (right hip) is hip flexion and, for the medial muscles (left hip) hip adduction.

1.2.2 FEMOROACETABULAR IMPINGEMENT SYNDROME (FAIS)

There are two types of anatomical morphology causing FAIS, i.e. cam morphology and pincer morphology (Figure 4). Cam morphology is found at the femoral head-neck junction and presents as a non-spherical femoral head, while pincer morphology is present when the acetabular rim extends and creates local or global over-coverage of the femoral head. These two types of morphology are also frequently seen together as a "mixed" type[10]. In the moving hip (particularly during flexion and IR), cam and/or pincer morphology can cause abnormal contact between the acetabulum and the femoral head-neck junction[11]. Repetitive abnormal contact, caused by cam morphology, leads to shear forces at the acetabular rim and chondral avulsion that can secondarily lead to labral and/or cartilage damage and delamination (Figure 5). The characteristic feature of pincer morphology is initial labral damage that may occur when the labrum is crushed between the acetabular rim and the femoral neck.

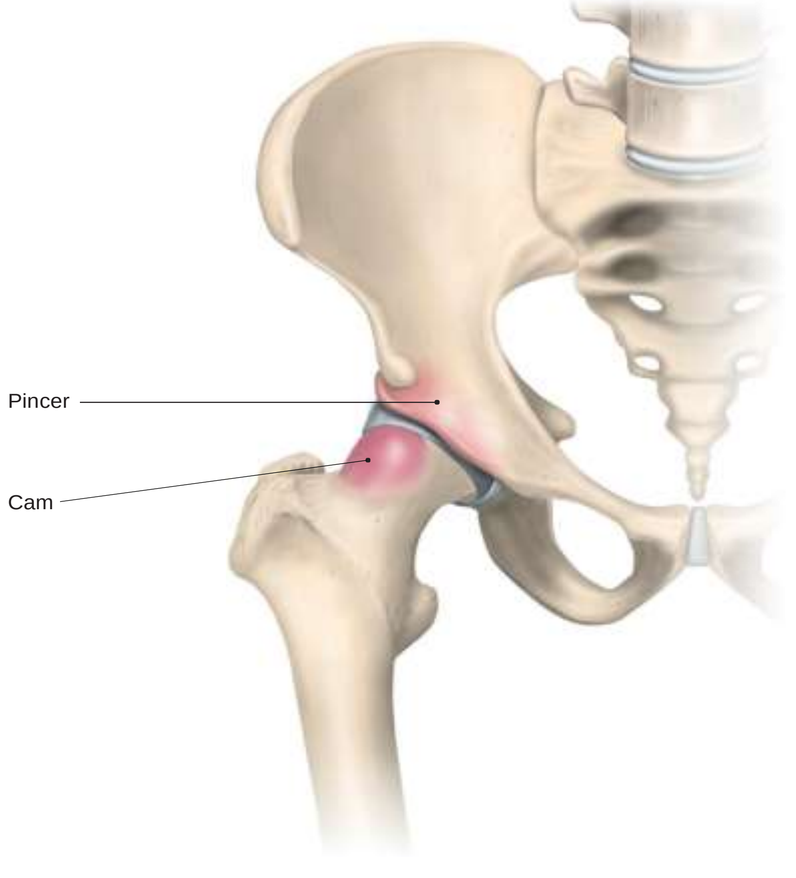

Figure 4. Cam morphology at the femoral head-neck junction and pincer morphology at the acetabulum.

Figure 5. Cartilage and labral damage due to cam morphology causing impingement when the hip is flexed and internally rotated. In this figure, a wave phenomenon and softening of the cartilage are shown.

The morphological features of FAIS can result in diminished hip function and hip pain and may affect a person's ability to participate in physical activity and sports, but not invariably. The diagnostic criteria for FAIS are only fulfilled when morphological changes, clinical findings and hip pain/symptoms are all present[2].

1.2.2.1 FAIS AND HIP OSTEOARTHRITIS

OA is a wide spread disease. In Sweden approximately every 4th person above 45 years of age has OA and hip OA was reported in 5% (second most common) of those seeking medical care for OA[12]. The etiology of OA is not well known and persons with OA are shown to have different causes of the disease. Known risk factors are age, genetics, gender, obesity and occupational aspects. Sporting activity has also been reported to increase the risk of hip OA[13,14]. Back in the 1930s, 1960s and 1970s, it was hypothesized that various hip morphologies led to degenerative changes in the hip joint[4,5,15]. However, it was the study by Ganz et al. in 2003[1] that proposed morphological changes related to FAIS as a definitive cause of hip OA and this led to multiple research studies in this area. Today, cam morphology is strongly considered to be a risk factor for the onset of hip OA[16-21]. The underlying mechanism by which cam morphology is able to initiate hip OA is thought to be related to cartilage overload causing articular cartilage degeneration. Although labral injury and cartilage damage are also seen in patients with pincer morphology, the same association with hip OA has not been found[22]. It is important to point out that everyone with cam morphology will not develop hip OA. The level of stress tolerance the articular surface has, and how quickly OA may develop, is still not known[23].

1.3 ETIOLOGY

Over the years, several theories have been proposed to explain the underlying cause of cam morphology. Genetic factors and pediatric conditions, such as a slipped capital femoral epiphysis (SCFE), have been discussed[24,25]. These two theories have, however, not been able to be definitively proven[26,27]. The theory of mechanical factors has thereby been proposed and is currently the most accepted theory as a cause of cam morphology, supported by several studies[27-31].

Back in 1971, Murray and Duncan found that young (17-21 years), mature and sports-active males were more likely to have a tilt deformity compared with their less active peers[32]. It was suggested that some kind of sports participation, especially during adolescence, could induce this hip deformity. Later, Agricola et al.[27] and Siebenrock et al.[29] proposed that high-impact loadings of the hips during a critical period of growth could cause cam morphology to develop. It is suggested that cam morphology is a structural adaptation at the proximal femoral growth plate, triggered by high external loads on the hips at the time at which the skeleton is most receptive to mechanical loads[28,33,34]. Cam morphology might therefore be a result of high-impact sporting activity during skeletal maturation. This is supported by several studies reporting an association be- tween cam morphology and high activity levels during adolescence[26,27,29,35-37]. Jónasson et al.[38] examined porcine hips after they were exposed to repetitive cyclic loading. They found injuries in and adjacent to the physeal plate and proposed that repetitive loads on the proximal femur may cause physeolysis or micro-fractures and thereby affect the vascular supply to the growth plate. This might therefore cause growth disturbance, since interrupted blood supply to the growth plate is a known factor that influences and disturbs physeal growth[39].

1.3.1EPIDEMIOLOGY/PREVALENCE

Hip and/or groin pain is common and FAIS is a frequent cause of the pain. The prevalence of FAIS in the population is not well known. One study reported an incidence of FAIS of 17% in a general population[40]. The radiological prevalence of cam morphology has, however, been reported in several studies, with some examples shown in Table 1. One systematic review reported a cumulative prevalence of 37% in asymptomatic hips in the general population[41]. In athletes, cam morphology is more common and this has been highlighted in one meta-analysis (athletic hips 41% vs. controls hips 17%)[42], one systematic review (athletic population 48-75% vs. general population 5-55%)[43] and numerous separate studies[29,35,37,44-59].

Some sports appear to be more exposed, where cutting (e.g. football, alpine skiing), contact sports (e.g. American football) and impingement sports (i.e. sports requiring high grades of flexion, adduction and IR; e.g. ice hockey) are highly represented[60-63]. Moreover, sports including supraphysiological movements of the hips (e.g. ballet, martial arts) are also suggested to be associated with cam morphology[58,60,61]. However, certain sports are more commonly investigated and others are not and may therefore be omitted. The type of hip movements or positions, loading directions or amounts that may predispose cam morphology to develop to greater degrees is not entirely known.

The highest rates of hip morphology related to FAIS have been shown in persons with hip/groin pain[63]. However, it has been shown that these morphologies are fairly com- mon in asymptomatic populations as well[47,64,65]. The association between cam morphology and hip pain is inconclusive. It is not known which individuals with cam morphology will develop hip pain and possible predictors of developing hip pain, are also not well known.

1.3.2 GENDER DIFFERENCES

Males appear to be more prone to develop cam morphology (13-72%) compared with females (0-12%)[47,64,66]. This might therefore propose a possible gender-specific pathogenesis. It might also be that, as the timing of maturation is earlier in females, they might be less exposed to high-impact sports at the time by which cam morphology develops. Males have been shown to have a generally larger cam morphology and greater intra-articular damage, while females more often score higher for self-reported dysfunction[67-69]. Females are also known to have greater general joint laxity[70,71], which may contribute to their reaching further in the hip movement that creates an impingement, despite a smaller cam morphology. The diagnostic criteria may therefore be different for males and females respectively.

Table 1. The prevalence of radiographic cam morphology based on varying α-angle cut-off values.

Study	Gender	n	Age, years*	Sport	Imaging modality‡	Prevalence of cam**	
						>55°	>60°
Agricola[44]	♂ ♂	77 93	15 14	Football Control	Frog leg		26% 17%
Gerhardt[46]	♂ ♀	75 20	26 24	Football	Frog leg	68% 50%	
Johnson[35]	♂ ♀ ♂ ♀	25 25 25 25	(18-30)	Football Control	Frog leg	60% 36% 56% 32%	
Mosler[54]	♂	438	26	Football	Dunn view		71%
Tak[56]	♂	60	23	Football	Frog leg		63%
Van Klij[57]	♂ ♂ ♂	89 62 49	15 17 21	Football	Frog leg		49%† 68%† 80%†
Lerebours[51]	♂	130	24	Ice hockey	Frog leg	69%	
Philippon[37]	♂ ♂	62 27	15 15	Ice hockey Alpine	MRI	75% 42%	
Larson[50]	♂	125		Am. football	Frog leg	75%	
Kolo[58]	♀	30	25	Dance	MRI	3%	
Fraser[59]	♀	30	17	Dance	Frog leg	18%†	
Mayes[53]	♂+♀ ♂+♀	33 33	17 17	Ballet Athletes	Dunn view		sup 0% ant 9% sup18% ant 9%
Langner[49]	♂ ♀	5 15	21	Water sports÷	MRI	40%† 27%†	
Mariconda[52]	♂+♀	24	32	Martial arts	Frog leg		46%†
Siebenrock[29]	♂	32	18	Basketball	MRI	89%†	
Aminoff[45]	♂ ♀ ♂ ♀	32 29 17 9	18 17	Alpine/Mogul Control	MRI	69% 28% 33% 12%	
Heijboer[48]	♂+♀	865	56	General population	AP pelvic, 15° hip IR		11%†
Gosvig[47]	♂ ♀	1184 2018	60	General population	AP pelvic		8.5%†† 3.5%††
Raveendran[55]	♂ ♀	1113 1483	63	General population	AP pelvic		18% 7%

Empty cells indicate data not reported. *Mean age in years. **Expressed as the percentage of subjects with an α-angle of >55° and >60°. ‡Frog leg, plain radiograph of the hip with the patient in a supine position and 45° hip abduction; Dunn view, plain radiograph of the hip with the patient in a supine position and the hip in 45° flexion and 20° abduction. ÷Include water polo and synchronized swimming. †The prevalence of cam morphology per hip. ††The prevalence is defined by an α-angle of >87° for males and >57° for females. ♂, males; ♀, females; ant, anterior location; sup, superior location.

1.4 ATHLETES

1.4.1EARLY SPORT SPECIALIZATION

Early sport specialization has been defined by the American Orthopaedic Society for Sports Medicine (AOSSM) as, from prepubertal age (roughly 12 years), participating in intensive organized training and/or competing sports for more than 8 months/year (essentially all year round) and participating in one particular sport to the exclusion of other sports (limited "free play")[72,73]. Increasing professionalism within youth sports and trends towards more frequent, intensive and structured sporting participation from early ages, have become more and more prominent in the last few decades. An underlying belief is that participation in structured training and competitive programs from increasingly young ages will help the athlete to reach elite level and careers with financial rewards or scholarships[72,74].

Sport and physical activity contribute to good health in the young and old, while early sport specialization has been associated with both physical and mental health concerns and/or injuries[75]. In addition to higher demands and loads on the growing body, sporting specialization also implies partial, monotonous and repetitive motions and exercises. This contributes to increased risks of acute and overuse injuries but also to growth-related disturbance and injuries such as epiphyseal fractures, avulsion injuries, apophysitis (e.g. Osgood-Schlatter) and cam morphology[74,76]. High injury rates have been reported among young athletes (Table 2)[77-87].

A common choice for young, ambitious athletes is to study at National Sporting Schools that offer an opportunity to combine high school or college education with elite sporting participation. The aim of the National Sports High School in Sweden emphasizes the investment in talents with the best qualifications to reach national or international elite level[88]. National Sports High Schools have been established since the 1970s in Sweden. However, their success in terms of senior elite sporting results and career length after graduation has been sparsely reported.

Table 2. Injury rate in young athletes at different national sporting schools/institutions.

Study	School/sport (study duration)	No. of subjects	Age*	Injury incidence**	Grade of injury***
Hildebrandt[77]	Ski boarding school (2 seasons)	104 ♂♀	15-19	0.67 acute†† 0.6 overuse††	
Jacobsson[78]	Track and field (n/a)	126 ♂♀	Mean: 17	3.1-3.9 injuries	25-39% sev.
LeGall[79]	National soccer training (>1 season)	119 ♀	15-19	6.4 injuries	12% sev. 36% mod.
LeGall[80]	National institute of football (3 years)	528 ♂	13-16	4.8 injuries	10% sev. 30% mod.
Müller[81]	Ski boarding school (2 years)	50 ♂ 31 ♀	9-14	0.63 acute†† 0.21 overuse††	18% sev. 45-47% mod.
Price[82]	Academy of football England (n/a)	4773 ♂	9-19	0.4 injuries†	22% sev. 44% mod.
Stiedl-Müller[83]	Ski boarding school (1 season)	50♂ 39♀	10-14	1.4 injuries 0.46 acute†† 0.13 overuse††	15% sev. 34% mod.
Von Rosen[84]	National sports high school (1 year)	284 ♂♀	16-18	4.1 injuries	22% sev.
Von Rosen[85]	Orientation national sport high school (6 months)	64 ♂♀	Mean: 17	18 injuries	
Westin[86]	Ski national sports high school (5 years)	215♂ 216♀	15-19	1.7 injuries	49% sev. 48% mod.
Yang[87]	College sports (3 years)			4.5 acute 1.9 overuse	

Empty cells indicate data not reported. *Age range in years unless specified. **Injury rate/1,000 athletic exposures/hours unless specified. ***sev., severe >1-2 months; mod., moderate 1-4 weeks. †injury/player/season, ††injury/subjects. ♀, females; ♂, males.

1.4.2 ALPINE AND MOGUL SKIING

Alpine and Mogul skiing are sports with high physical demands, with continuous, rapid adaptations to terrain variations, slopes, moguls, gate setups and snow conditions. This implies a complex motor activity imposing varied demands on muscle performance, coping and neuromuscular control to maintain posture[89,90]. The movement pattern differs between Alpine and Mogul skiing, where both are mainly performed in a squatting position, including high impacts and heavy loads on the hips and spine. Alpine skiers often seek to minimize aerodynamic drag with a "crunching" position with spinal, hip and knee flexion. This is combined with a constant change of hip movement, from extended to al- most fully flexed and internal to external rotation. Mogul skiers have a more upright spinal position, with the hips and knees in a more or less constant flexed position, combined with intermittent whole-body changes to perform aerial maneuvers and landings over the bigger jumps[89,91]. Both Alpine and Mogul skiing require large-scale physical fitness, including strength, endurance and power but also balance and coordination.

The same trend has been seen in Alpine and Mogul skiing, as in other sports, with more early sport specialization[92]. A high risk of injuries has been reported in both senior and junior elite skiers[77,81,83,86,93]. Recent studies have also shown higher proportions of radiological changes in the lumbar spine and hip joints in adolescent elite skiers, compared with non-athletes[45,94,95]. The way these changes may or may not affect skiers in the long term is not known.

1.4.3 FOOTBALL

Football (soccer) is one of the most popular sports in the world and is performed by males and females, children and adults. Football players need to have high aerobic and anaerobic capacity, good agility, sufficient muscular development and flexibility in several joints[96]. During a game, the field player covers approximately 10-12 km. However, most of the time (approximately 85%) during a game is of low intensity, including jogging, walking or standing still, while the rest includes high-intensity activities[97]. The latter implies sprint bouts, twists, turns and jumps, pace changes and forceful contractions to maintain balance and control and several passes and shots. Training sessions often involve more high-intensity play in smaller areas, ball contacts, running with the ball, starts, turns, jumps and tackles.

In both skiing and football, well-designed strength-training programs are natural complements to their specific sports training, where axial loading exercises, such as squats, cleans, snatches and deadlifts, are common[98]. These exercises may not only lead to strength gains but might also lead to acute or overuse injuries if the progression is too rapid and/or the technique is inferior. Exercises including deep hip flexion (e.g. squats) may also predispose to the collision between femur and acetabulum, characteristics in cam morphology[99].

1.5 THE EVALUATION OF FAIS

In conjunction with the growing interest and research in the field of FAIS and its morphologies, inconsistent and different definitions of symptoms, clinical findings and diagnostic radiology have been used. A consensus meeting was therefore held in Warwick, United Kingdom, in 2012, and *the Warwick Agreement on femoroacetabular impingement syndrome (FAI syndrome): an international consensus statement* was thereafter published in 2016. According to this, the diagnosis of FAIS should be based on a mixture of radiological findings, clinical signs and symptoms and should not be dependent on a single test, finding or symptom[2].

1.5.1 RADIOLOGICAL EXAMINATION

Radiological imaging can confirm morphological variations related to FAIS. Plain radiographs, magnetic resonance imaging (MRI) or computed tomography (CT) are all able to visualize the presence of cam morphology[2]. The non-spherical shape of the femoral head defines cam morphology and is most commonly seen at the supero-anterior part of the femoral head-neck junction[29,64,100]. Dunn's view or the Lauenstein view are therefore preferable, but the antero-posterior (AP) pelvic view and lateral femoral view are usually sufficient, when plain radiographs are used[101]. Plain radiographs are also defined as the "gold standard" to detect OA. MRI has the advantage of being able to detect possible injuries to tendons, cartilage and labrum that may cause hip pain. MRI is also preferable in young and growing cohorts to prevent unnecessary radiation. Siebenrock et al.[29] created an MRI method aimed at covering the entire cranial hemisphere of the femoral head (posterior-superior-anterior), where the 1 o'clock position mainly represents the supero-anterior part (Figure 6).

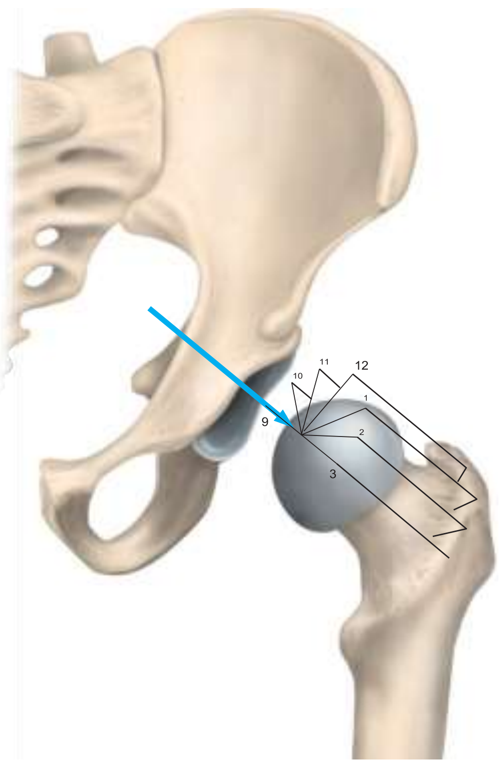

Figure 6. Radial cuts rotating clockwise in 30° intervals perpendicular to the femoral head-neck axis, giving seven positions from 9 o'clock (posterior) to 3 o'clock (anterior).

The α-angle is the most accepted method for expressing and quantifying the presence and size of cam morphology (Figure 7)[102]. Cut-off values of the α-angle equal to or above 55-60° are often used to define the presence of cam morphology[29,37,54]. How- ever, there is a wide variation between studies (50-83°), leaving questions about which cut-off value might lead to the development of symptoms and dysfunction related to FAIS, or possible hip OA later in life. In addition, as FAIS appears to be multifactorial, determining a definite cut-off value for the α-angle is problematic.[101]

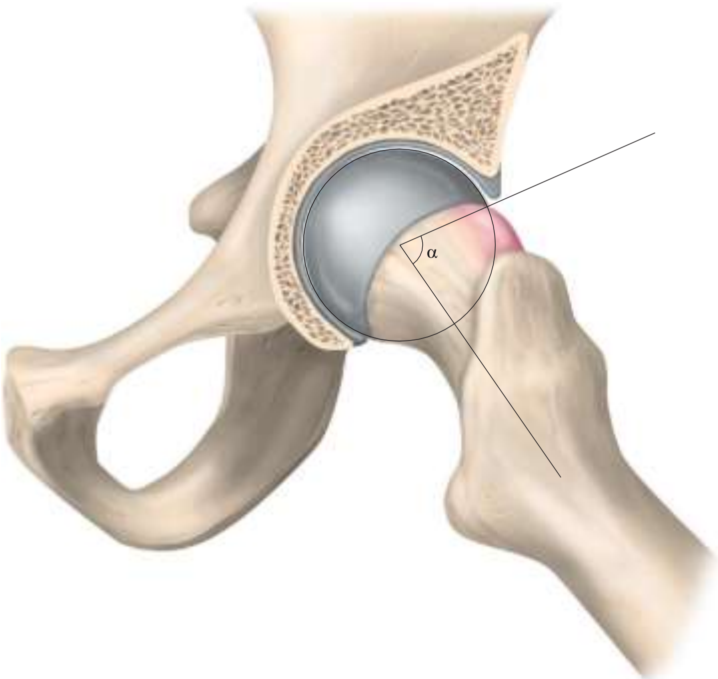

Figure 7. The α-angle is measured between a line drawn along the center of the femoral neck and a line drawn to the point at which the bone breaks through a best-fit circle around the femoral head. The α-angle in this figure is 80°.

1.5.2 CLINICAL EXAMINATION

> *"Diagnosis of FAI syndrome does not depend on a single clinical sign; many have been described and are used in clinical practice"*
>
> – THE WARWICK AGREEMENT [2]

Several hip impingement tests have been reported and have the purpose of reproducing the typical pain that the patient recognizes. The Flexion Adduction Internal Rotation (FADIR) test (Figure 8), also known as the Anterior hip impingement test, is the most commonly used and it is recommended as a part of the clinical examination[2]. This test is considered positive if it reproduces the patients' symptoms. The test has shown fairly good sensitivity, while specificity is somewhat low[103]. The Flexion Abduction External Rotation (FABER) test is also regularly used in patients with hip pain (See methods, Figure 14). Reduced hip ROM (measured by the angle or distance to the table) and/ or reproducing the patient's symptoms are regarded as positive. The test was initially created to detect sacro-iliac joint dysfunction and it has shown moderate to good sensitivity but low to very low specificity and it is currently recommended as a test of multi-directional ROM in the hip joint rather than a means of detecting possible intra-articular pathology[2,103].

Figure 8. The FADIR test in the supine position with the leg that is being tested taken into hip and knee flexion, internally rotated and adducted until resistance or pain/discomfort.

Reduced hip-joint ROM, particularly hip flexion and IR in 90° flexion, is thought to be associated with FAIS[2]. However, there is a discrepancy in the literature if patients with cam morphology and FAIS have reduced hip ROM compared with healthy subjects or compared with their unaffected hip[104,105]. It is also important to interpret reduced hip ROM cautiously, as this is a clinical sign of OA as well. In spite of this, examinations of hip ROM are recommended when FAIS is suspected, in addition to hip muscle strength and tenderness, gait, single-leg balance and hip impingement tests[2].

Hip ROM can be quickly and directly examined using a non-invasive universal goniometer (UG). This is the device most commonly used to measure joint ROM in clinical settings, with good validity and high reliability (Table 3)[104,106-108]. However, there are some major drawbacks to the UG, such as the true starting point, vertical and horizontal positions and also the fact that the center of rotation is only visually estimated. Moreover, the UG needs to be held with two hands, with no hand free for stabilization the body or the proximal joint, making larger joints, such as the hip, more difficult to measure. A digital goniometer (DG) may therefore be a useful complement. The DG has shown good validity and agreement with both the UG and the inclinometer, as well as high test-retest reliability (Table 4)[106,109,110].

Table 3. Reliability and validity of the universal goniometer.

Study	Cohort (joint)	Reliability*		Validity**	
		ROM	Intra/inter	vs. device	ROM
Carey[106]	Healthy (shoulder)	IR ER	Intra: 0.7-0.9† Inter: 0.60† Intra: 0.4-0.8† Inter: 0.46†	DG	IR: ns ER: ns
Holm[107]	OA (hip)	Flex IR pro ER pro	Intra: 0.82 Intra: 0.90 Intra: 0.90		
Nussbaumer[104]	FAIS, Healthy (hip)	Flex IR sup ER sup	Intra: 0.91 Intra: 0.95 Intra: 0.91	Electro-track system	Flex: 0.44 IR: 0.88 ER: 0.54
Roach[108]	Healthy (hip)	IR pro ER pro	Intra: 0.80 Intra: 0.80	Inclino-meter***	IR: +4.5°†† ER: -5.0°††

Empty cells indicate data not reported. *Intra- or inter-rater reliability in ICC unless specified. **Validity as compared with other devices in ICC unless specified. ***Inclinometer, a portable, lightweight digital device measuring ROM, calibrated and zeroed based on the gravity. †Intra-rater reliability measured with the Pearson product-moment correlation coefficient. ††Mean difference in degrees between devices. Flex, flexion; IR, internal rotation; ER, external rotation; sup, supine; pro; prone; ns, no significant difference between devices.

Table 4. Reliability and validity of the digital goniometer.

Study	Cohort (joint)	Reliability*		Validity**	
		ROM	Intra/inter	vs. device	ROM
Carey[106]	Healthy (shoulder)	IR ER	Intra: 0.8-0.9† Inter: 0.62† Intra: 0.8-0.9† Inter: 0.53†	UG	IR: ns ER: ns
Forde[109]	Healthy (ankle)	Dorsiflex Inversion Eversion	Intra: 0.87 Inter: 0.89 Intra: 0.90 Inter: 0.87 Intra: 0.67 Inter: 0.69	Tracto-graph‡	Dorsiflex: 0.90 Inversion: 0.89 Eversion: 0.79
Furness[110]	Healthy (shoulder)	IR‡‡ ER‡‡	Intra: 0.8-0.9 Intra: 0.8-0.9	Inclino-meter	IR: 0.87 ER: 0.72

*Intra- or inter-rater reliability in ICC unless specified. **Validity as compared with other devices in ICC unless specified. †Intra-rater reliability measured with the Pearson product-moment correlation coefficient. ‡Tractograph, a two-armed goniometer with 15cm arms. ‡‡Active ROM IR, internal rotation; ER, external rotation; ns, no significant difference between devices.

1.5.3 SYMPTOMS

Symptoms related to FAIS are similar to those of degenerative disease in the hip joint, where pain is the primary symptom. Most commonly, the pain is located in the groin or deep in the hip, but it may also be felt in the buttock, thigh or lower back. It is often reported as motion- or positioning-related pain, present during or after physical activity, prolonged sitting or in other specific situations including hip flexion and IR or supraphysiological hip ROMs[2,58]. Sometimes, patients also describe symptoms such as catching, clicking, locking, stiffness, ROM restrictions or even giving-way.

1.6 TREATMENT OF FAIS

Not all patients with cam morphology develop FAIS, but for those who do, the treatment options are either surgical or non-surgical. Two large RCTs have compared surgical with non-surgical treatment for FAIS, showing certain advantages for the surgical intervention[111,112]. However, these results can be questioned with regard to the lack of sufficient data about the actual training, frequency of training, its content (strength, balance, ROM) and how progression was managed in the non-surgical treatment groups. These are all fundamental parameters, as a certain dosage (in terms of both frequency and intensity/progression) is needed to increase muscle strength and dysfunction[113]. Whether the two treatment approaches affect the development or prevention of OA is not clear. Considering that there are some risks with surgery and that symptoms may not only be caused by the bony anatomical features of cam morphology, it is therefore suggested that non-surgical treatment for FAIS should be considered as the first line of treatment.

1.6.1NON-SURGICAL TREATMENT & PHYSICAL THERAPY

The primary aim of non-surgical treatment is to reduce hip pain and achieve a safe and pain-free hip ROM, preferably without sacrificing activity level. In general, this treatment includes activity modification, patient education, non-steroidal anti-inflammatory drugs (NSAIDs) and physical therapy. Despite the fact that physical therapy is advocated as the first-line treatment in patients with FAIS, guidelines and evidence on how this treatment should be performed, or what to include, are still lacking. This is reflected by the contraindicatory results, in terms of its efficiency, that have been reported as ranging from favorable[114,115] to less favorable[116].

Studies have shown that patients with FAIS have reduced hip muscle strength and different biomechanics during functional activities compared with controls or their non-affected hip[105,117]. These are therefore potential goals in the physical-therapeutic treatment. The most common recommendations that are being reported include the avoidance of passive and/or hard-end ROM stretches (particularly if painful) and an in- crease in hip and core muscle strength and stability, hip muscle flexibility, motor control and posture[118]. All these elements may facilitate the better positioning of the hip joint, thereby reducing the risk of mechanical contacts between the acetabulum and the femoral head-neck junction manifested in FAIS patients[118].

Furthermore, Bagwell et al. found a more anteriorly tilted pelvis, in a cohort with FAIS as compared with controls, during a squat exercise, which may predispose to an im-pingement[99]. Squats are widely used not just in the context of many sports, but also in activities of daily living. Studies suggest that it is important that the patient receives an education in good techniques in both sport-specific and daily activities, to minimize possible impingement-positions that may cause hip pain to develop or increase.

1.6.2 SURGICAL TREATMENT

If non-surgical treatment fails, surgery at an early stage should be considered in order to prevent possible other damage to the hip joint, but also in order to implement short- er symptom duration and an improved functional outcome[119,120]. Surgical treatment is based on the notion of resecting cam/pincer morphology to restore normal hip-joint anatomy, and thereby increasing joint congruency. It aims also to reduce hip pain and treat possible labral and/or cartilage damage and possibly prevent or delay the onset or progression of end-stage OA[2]. An open technique, which included hip dislocation, was initially used to treat FAIS[121] and a mini-invasive arthroscopic technique was first reported in 2005[122]. Overall, arthroscopic treatment for FAIS has been shown to provide good results at short, mid and long term[119,120,123]. However, favorable results of this kind are based on group level reports, while, at individual level, the outcomes are shown to have considerable variations. Whether surgery will reduce the risk of hip OA is unclear. Some reports on survival rates, defined as conversion to total hip arthroplasty (THA), have shown rates of between 83 and 84% at a mean of 5-7 years after surgery for

FAIS. It has also been shown that older age, signs of OA and severe cartilage lesions at the time of surgery increase the risk of THA.[123,124]

Postoperative regimens may differ based on surgical methods and the severity of lesions inside the hip joint that need to be managed (e.g. resect or repair/reconstruct the labrum, microfracture of cartilage damage). Commonly, the patient needs to ambulate using crutches for four weeks, with or without restricted weight-bearing, and is allowed either free ROM or with restrictions of abduction and external rotation (ER) during the first weeks. To minimize the risk of heterotopic ossification, NSAIDs are often prescribed during the first weeks. Physical therapy is started directly postoperatively with exercises for ROM, strength, endurance, coordination and balance gradually increasing based on patient tolerance.

1.6.3 EVALUATION OF TREATMENT

To evaluate treatment interventions, both objective and subjective measurements are available and provide a great deal of valuable information. Objective evaluation includes radiological imaging, ROM, muscle strength and functional tests, while patient-reported outcome measures (PROMs) and interviews are examples of subjective evaluations. Objective and subjective outcomes may not necessarily match each other; for example, a larger ROM may also be concomitant with an increased level of pain. It is therefore preferable to use both methods in the evaluation of FAIS.

In the last few years, multiple PROMs have been developed and validated for the young (and middle-aged) active population. *The International Hip Outcome Tool* (iHOT) and *The Copenhagen Hip and Groin Outcome Score* (HAGOS) are two examples of PROMs that have been recommended in the evaluation of patients with FAIS[2]. The iHOT con- sists of 33 questions, but it is now available in a short version comprising 12 questions (iHOT-12). The answers are marked on a Visual Analogue Scale (VAS) and a total score ranging between 0-100, where 100 implies best score/no problems, is calculated. The HAGOS consists of 37 items with six subscales: symptoms and stiffness; pain; activity of daily living (ADL); sports/recreational activities; physical activity participation (PA) and hip/groin-related quality of life (QoL). The answers are marked on a 5-level Likert scale (0=best; 4=worst) and each subgroup has separately calculated scores ranging between 0-100, where 100 implies the best score. *The Hip Sports Activity Scale* (HSAS) was developed for patients with FAIS to measure physical activity. It consists of nine different levels of sports activity ranging from 0 (no recreational or competitive sports) to 8 (competitive sports (elite level)). *The Back and hip questionnaire* focuses on present and previous low back pain and hip pain related to their nature, location, onset, du- ration and severity of pain (graded with VAS) and in the context of present and previous factors of daily living, work, training and competing. The HSAS, iHOT-12 and HAGOS have been adapted and validated to Swedish, with good reliability and validity being reported[125-127]. The HSAS, iHOT-12 and HAGOS are found in the Appendix.

1.6.3.1 RETURN TO SPORT

Since FAIS is a diagnosis largely affecting athletes, the goal of many patients (and treating clinicians) is to return to sport (RTS). Several studies and systematic reviews have reported rates of RTS after surgical treatment, but reports of RTS after non-surgical treatment for FAIS are lacking. Three systematic reviews have reported rates of RTS and RTS to pre-injury sporting level (RTS^{pre}) after surgery for FAIS between 87-92% and 74-88% respectively[60,128,129]. However, recent studies have reported lesser rates of RTS (28%) and RTS^{pre} (19-21%)[130,131]. Moreover, in their study, Ishöi et al. found that the rate of RTS^{pre} was 57%, but only 30% of these (17% of the total study population) estimated themselves as being at their optimal performance level[132].

The discrepancy between studies is probably related to the wide variation in the cri- teria and methods used to investigate RTS, or the lack of clear definitions of RTS. In a consensus statement, Ardern et al. suggest that RTS can be seen as a continuum and define three elements that emphasize a graded and criterion-based progression (Figure 9)[133]. Even though this definition of RTS and RTS^{pre} provides effective guidelines and may contribute to greater consistency between studies, there is also a timing aspect to bear in mind. Is RTS^{pre} successful if the athlete is able to participate for one game, one month or even one season at his/her best performance but then has to finish due to recurrent hip symptoms?

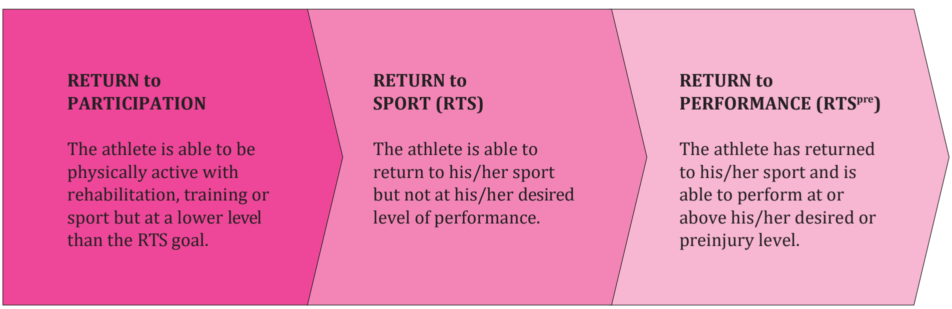

Figure 9. The continuum of return to sports (RTS) according to Ardern et al.[133]

2

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AIMS

At present, it is thought that the development of cam morphology is greatly affected by participation in high-impact sports during skeletal maturation[27,36]. While the prevalence of cam morphology is high among athletes[42], the prevalence of FAIS is not well reported. Despite the fact that hip pain and reduced hip ROM are parts of the diagnostic criteria for FAIS, their association with cam morphology has been questioned, with conflicting evidence being reported. The reason why some athletes with cam morphology may function well at a high level for many years, without having hip pain or any secondary injuries/dysfunction related to FAIS, while others do not, is not well known.

Males appear to be more prone to develop cam morphology compared with females, while females have been shown to have more self-reported hip pain and dysfunction to lower levels of cam morphology[67]. This suggests that a gender-specific pathogenesis may be possible, or that females participate in sports that are not as well studied. Furthermore, certain sports are more commonly investigated than others, with regard to the prevalence of cam morphology, leaving gaps in knowledge.

Arthroscopy is an increasingly common treatment for FAIS, with good outcomes and high rates of return to sports being reported. However, there is still an unsolved question related to the athletes' ability to return to, and continue to remain at, their pre-injury level of sports and whether this differs between sports and genders.

Comparing genders and different groups of athletes and nationalities, at different points in time, may provide a further understanding of the etiology and treatment of cam morphology and FAIS.

SPECIFIC AIMS OF THIS THESIS

Study I	To compare the prevalence of cam morphology, pain and range of motion in the hip joint between young male football players and young male and female skiers, and also to investigate who will fulfill the diagnostic criteria for FAIS.
Study II	To investigate how hip-joint range of motion is affected by continued skiing in young elite skiers with and without cam morphology, over a period of two years.
Study III	To investigate the correlation between cam morphology, hip pain and activity level in young elite skiers over a period of 5 years.
Study IV	To investigate gender differences in the types of sport that are most frequently performed by competitive athletes who have undergone hip arthroscopy for FAIS and also investigate preoperative hip symptoms and function using PROMs.
Study V	To investigate the rate of competitive high-level athletes who have returned to, and still are at, their pre-injury level of sports two years after arthroscopic treatment for FAIS and to compare the return rate between sports, genders and PROMs.

3

METHODS

STUDY SAMPLE

STUDIES I, II AND III

The sample group (n=136) comprised 76 young skiers (Alpine and Mogul) and 60 young football players. The inclusion criterion was being active in their sport at elite level, i.e. training and competing at national or international level in their particular age group. The exclusion criteria were any previously diagnosed injury and/or surgery to the hip, pelvis or lumbar spine, or pregnancy. One skier was excluded before study start due to hip surgery. The skiers were pupils at the Åre Ski Academy (National Sports High School), Östersund, Sweden, and the football players were from the Icelandic U16 National team and FC Barcelona U16 team. All students in Grades 1-4 and all football players in each team were invited and agreed to participate.

Study I included skiers in Grades 1-4 (n=75, age range 15-21 years), Icelandic football players (n=30, age range 16-18 years) and Barcelona football players (n=30, age range 15-18 years). Study II included skiers in Grades 1-2 (n=35, age range 16-18 years), while Study III included the same skiers as in Study I.

STUDIES IV AND V

Athletes at pre-injury competitive level were identified in the Gothenburg Hip Arthroscopy Registry. This registry prospectively includes all hip arthroscopies performed at two orthopedic centers in Gothenburg, Sweden. The inclusion criteria were pre-injury (i.e. before hip pain onset) sporting participation at competitive level, undergoing arthroscopic treatment for FAIS (i.e. cam and/or pincer resection) between December 2011 and March 2019 (Study IV) and from December 2011 to March 2017 (Study V) and having recorded data for the types of sport in which they were active (Figure 10).

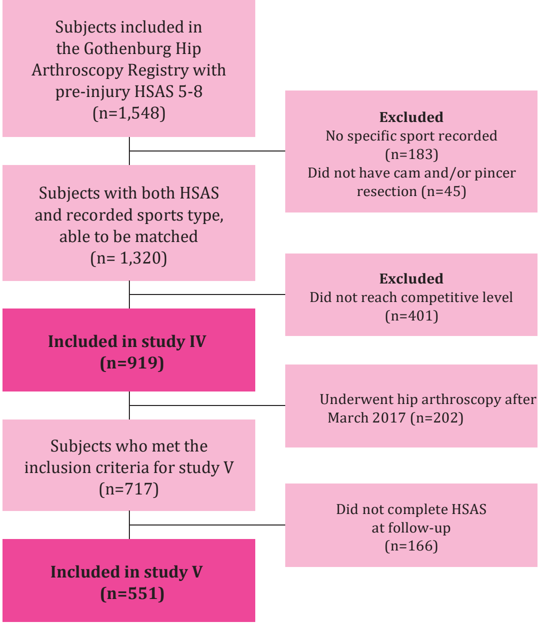


Figure 10. Flow-chart of participants in Studies IV and V.

To identify athletes at pre-injury competitive level, their HSAS before the onset of initial hip pain (i.e. pre-injury) was matched to their self-reported sporting activity. To clarify, a golf player who scored HSAS 6 was classified as being at competitive level, while an ice-hockey player who scored HSAS 6 only reached recreational level and was therefore excluded. The exclusion criteria were athletes with missing data on pre-injury HSAS score, self-reported sporting type, or not reaching competitive level. Contraindications for the arthroscopy were advanced OA (joint space <2 mm) and severe dysplasia (lateral center-edge angle <20°), but they were not deemed to be solid exclusion criteria.

STUDY I

This is a comparative cross-sectional study with clinical and MRI examinations and self-reported questionnaires filled out between 2014 and 2015. Comparisons were made between young elite athletes including male skiers (n=40), Icelandic male football players (n=30), male football players from FC Barcelona (n=30) and female skiers (n=35). The comparisons included the prevalence of cam morphology, hip-joint ROM (flexion, IR and ER), the FADIR test, hip pain, activity level and age of debut for training and competing. The proportions of athletes that fulfilled the diagnostic criteria for FAIS (MRI measurement of the α-angle ≥55°, self-reported hip pain and reduced IR (<25°)[134] and/or positive FADIR test) were also calculated. None of the Barcelona players had an MRI examination due to logistics.

CLINICAL EXAMINATION

The clinical examination was standardized and was performed in the following order: hip flexion, IR, the FADIR test and ER (Figures 8, 11-13). The same two collaborating examiners performed all the clinical testing of the skiers at the Åre Ski Academy, Östersund, Sweden, for the Icelandic football players at the Icelandic Heart Association, Hjartavernd, Kópavogur, Iceland, and for the Barcelona football players at their training center in Barcelona, Spain.

All hip-joint ROM angles were measured in degrees at the end-point of initial resistance using both a UG with extended arms (40cm) and a DG (HALO, medical devices, Australia). Reference points for the measurements were chosen according to Clarkson[135]. The DG was calibrated and zeroed before each test and it was then held with laser beams along either reference line 1, from the lateral femoral condyle to the greater trochanter, or line 2, from the apex patellae to midway between the medial and lateral malleolus. In the case of disagreement between the two devices, the value recorded by the UG was used. Test-retest examinations were performed for intra-observer reliability on 10 skiers, with four months passed between the test occasions. Inter-observer tests were also performed on 10 skiers, on the same day. Intra-observer and inter-observer reliability were calculated with ICCs (intraclass correlation coefficient) of 0.77-0.82 (good agreement) and 0.83-0.94 (good-excellent agreement) respectively[136].

Figure 11. Hip flexion in the supine position (Studies I-II). The leg that is tested is flexed at the hip and knee by one examiner, while maintaining pressure on the contralateral thigh, preventing pelvic rotation. Reference line 2 is used for the DG measurement (pink line at the thigh).

Figure 12. Internal rotation in the supine position (IR) (Studies I-II). The hip and knee are held at 90° flexion and are then internally rotated by one examiner, while the other examiner stabilizes the subject's iliac crest. Reference line 1 is used for the DG measurement (pink line at the leg).

Figure 13. Internal (IRsit) (Study II) and external rotation (ER) (Studies I-II) in a neutral sitting position, with arms across the chest and a 1-cm pad underneath the distal femur. One examiner internally rotates the tested leg, while the other stabilizes the thigh and iliac crest. The same hip is then rotated externally. Reference line 2 is used for the DG measurements (pink line at the leg).

MRI EXAMINATION AND EVALUATION

The athletes underwent MRI examinations on both hips, according to the same imaging protocol. The skiers had their MRI examinations at the Radiographic Department at Östersund Hospital, Sweden, using an MRI scanner, the GE Optima 450 Wide 1.5T. The Icelandic football players had their MRI examinations at the Icelandic Heart Association, Hjartavernd, Kópavogur, Iceland, using an MRI scanner, the Signa Twin-speed; EXCITE 16-channel system 1.5T. By using a coil surface of HD 8ch cardiac array, coronal T2 fat-saturated and axial 3D cube sequences were taken angled at the femoral neck in all MRIs. The MRI scans were evaluated and measured unidentified by two radiologists.

Inter-observer reliability was tested between the two radiologists of 15 randomly selected skiers and football players MRI scans. An ICC of 0.46-0.81 (poor to good) was shown. Intra-observer reliability was tested by repeated measurements of 15 randomly selected MRI scans, with four weeks between, showing an ICC of 0.83-0.97 (good to excellent)[136].

THE α-ANGLE

The α-angle was measured on the MRI scans (Figure 7) according to Nötzli et al.[102]. This was repeated in seven clockwise radial images in 30° intervals around the proximal femur, from posterior (9 o'clock) to anterior (3 o'clock), as described by Siebenrock et al.[29] (Figure 6). Cam morphology was regarded as present with an α-angle of ≥55° at any of the seven locations.

THE GROWTH PLATE

Based on the background by which it has been reported that cam morphology develops at the time of physeal closure[27,29,36], an examination to determine whether the femoral growth plate was open or closed was performed on the MRI scans, as described by Siebenrock et al.[29]. Skeletal maturation was judged in relation to the presence of the capital femoral physis.

QUESTIONNAIRE

All the participants answered the Back and hip questionnaire that has been used in several previous studies[95,137,138]. It includes questions on the prevalence of hip pain present and past, types of sport that are performed, present activity level and frequency and age of debut for training and competing.

STATISTICAL ANALYSIS

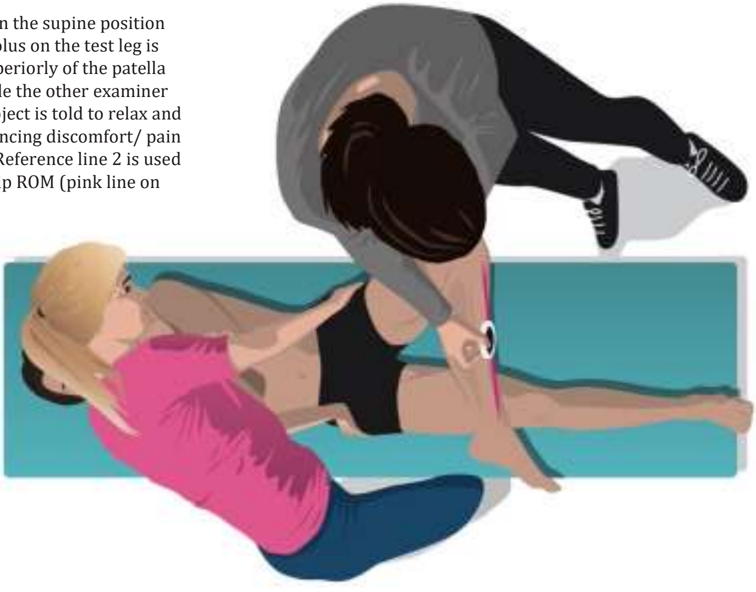
The Shapiro-Wilk normality test was used for normal distribution analysis. The data were expressed as numbers and percentages (%) or in terms of the mean and standard deviation (SD), unless otherwise specified. The chi^2 test was used for categorical data comparisons. An independent *t* test or one-way ANOVA with a Bonferroni post-hoc test used for comparisons of continuous data between groups. The significance level was set at $P<0.05$.

STUDY II

This is a cohort study with a 2-year follow-up. MRI examinations of the presence of cam morphology were completed at baseline (2014) and clinical examinations of hip ROM (flexion, IR, the FABER test, IR in sitting position (IR^{sit}) and ER) were performed at baseline and at the 2-year follow-up (2016). Hip ROM was compared between baseline and the follow-up and between skiers with and without (no-cam) cam morphology. Only skiers with both baseline and follow-up data were included for final analysis.

The same two collaborating examiners performed all the clinical testing standardized as in Study I, with the addition of the FABER test (Figure 14), as described by Ross et al.[140] and IR^{sit} (Figure 13) at the Åre Ski Academy, Östersund, Sweden. The MRI examination was performed according to the same imaging protocol as in Study I, at the Radiographic Department at Östersund Hospital, Sweden. The MRI scans were evaluated and measured anonymous by one radiologist. The inter-observer reliability was previously reported to be 0.75 in this cohort[141].

Figure 14. The FABER test in the supine position (Study II). The lateral malleolus on the test leg is placed, by one examiner, superiorly of the patella on the contralateral leg, while the other examiner stabilizes the pelvis. The subject is told to relax and lower the knee until experiencing discomfort/ pain or the end-point of motion. Reference line 2 is used of the DG measurement of hip ROM (pink line on the leg).



STATISTICAL ANALYSIS

All the hips were analyzed separately, divided into groups of cam and no-cam and stratified by right and left hip. Continuous data were expressed in terms of the mean and SD. Normal distribution was tested with the Kolmogorov-Smirnov test. A paired *t* test was used to compare between baseline and the 2-year follow-up. An independent *t* test was used to compare between the cam and no-cam group. Categorical data were expressed as frequencies and percentages (%), using the chi^2 test to compare data. The significance level was set at $P<0.05$.

STUDY III

This cohort study with a 5-year follow-up comprised elite skiers (n=75). At baseline in 2014, MRIs were evaluated for the presence and size of cam morphology and the participants answered the Back and hip questionnaire. The MRI examination and the questionnaire were the same as in Study I. In 2020, the skiers were re-contacted by telephone and asked to answer a shortened version of the Back and hip questionnaire. The following questions were included in the shortened version *Do you have, or have you had, hip pain in the right and left hip respectively?* ('Yes, at present', 'Yes, previously, but not now', 'No, never'), *Grade your hip pain ('mild', 'moderate', 'severe'), Try to describe your hip pain:___________________________, How do you exercise/train at present? How many days/week do you exercise? Are you active in your main special sport?* ('Yes, competing', 'Yes, recreational/coaching', 'No'). If the skiers did not answer "Yes, competing" to this last question, an additional question related to the reason why they were not still competing was asked.

STATISTICAL ANALYSIS

The Shapiro-Wilk test was used to test the normal distribution. For continuous variables, the mean and SD described the data and an independent *t* test was used for comparisons. Categorical data were expressed with frequencies and percentages (%), and the chi^2 test was used for comparisons. The McNemar test or paired *t* test was used to compare data between the baseline and follow-up. Spearman's rank-order correlation test (r_s) was used for correlation analysis between hip pain and cam morphology. Values between 0.9-1.0 indicate very high correlation; 0.7-0.9 high correlation; 0.5-0.7 moderate correlation; 0.3-0.5 low correlation and <0.3 negligible correlation[139]. A subgroup analysis was performed including skiers who were pain free at baseline. The significance level was set at $P<0.05$.

STUDY IV

This is a retrospective cross-sectional study with prospectively collected data. The patients completed web-based, self-administered PROMs of hip-related symptoms and function, including the iHOT-12, the HAGOS six subscales and the HSAS (pre-injury score) preoperatively. The patients also reported the types of sports that they perform/-ed.

The indication for hip arthroscopy was a combination of hip pain, a positive FADIR test, painful IR, positive radiologic criteria for FAIS (α-angle, crossover sign and/or pistol grip deformity) and failed non-surgical treatment. No specific cut-off value for the radiographic criteria was used and it was left to the surgeon to decide. Perioperatively, the surgeon reported the performed procedure (cam, pincer or mixed resection). The surgical technique has previously been described by Sansone et al.[142]. The patients were allowed free ROM and full weight-bearing with a recommendation to use two crutches for four weeks after surgery in outdoor and longer ambulation. Physical therapy started directly postoperatively and the rehabilitation protocol included exercises for ROM and the gradual progression of strength, endurance, balance and coordination exercises, as tolerated by the patient.

STATISTICAL ANALYSIS

The Kolmogorov-Smirnov test was used to test the normal distribution and, due to skewed data, descriptive results were presented as the median (interquartile range Q_{25}-Q_{75}, IQR), unless otherwise stated. For comparisons of preoperative data between genders, the Mann Whitney U test and the chi^2 test (for categorical data) were used. The significance level was set at $P<0.05$.

STUDY V

This is a retrospective cohort study with a 2-year follow-up, using prospectively collected data. Preoperatively, all the patients reported their sporting activity and filled out self-administered, web-based PROMs, including the iHOT-12, the six subscales of HAGOS and their pre-injury HSAS score. At 1-2 years postoperatively, the patients filled out the same set of web-based PROMs, except that the HSAS was scored with regard to their present activity level.

RTS^{pre} was defined by athletes who obtained the same or a higher HSAS score at the follow-up as compared with their pre-injury HSAS score, while noRTS was defined by athletes who did not reach their pre-injury level, i.e. had lower scores at the follow-up as compared with their pre-injury HSAS score. Only data from athletes with both HSAS scores pre-injury and at the follow-up were used. The indication for and details of the arthroscopic treatment made were the same as in Study IV.

STATISTICAL ANALYSIS

The data had skewed distribution, tested with the Kolmogorov-Smirnov test, and descriptive results were therefore presented as the median (IQR), unless otherwise stated. Wilcoxon's signed rank test was used for repeated measurements between baseline and the follow-up. The Mann-Whitney U test was used for continuous variable comparisons and the chi^2 test for comparisons of categorical data. To assess clinically relevant change, the minimal important change (MIC) was used for the HAGOS six subscales and the iHOT-12. The MIC has previously been described as being 9.3 for HAGOS symptoms, pain 9.7, ADL 11.8, sports 10.8, PA 13.1 and QoL 8.8[126] and with 9.0 for iHOT-12[125]. The patient acceptable symptomatic state (PASS) was also used for iHOT-12 and has been described as 63.0[143]. The significance level was set at $P<0.05$.

3.1 ETHICAL ASPECTS

Studies I-III involved both clinical and MRI examinations. Written and oral information relating to the studies was given in advance and written consent forms were signed by all the subjects and by one parent for subjects younger than 18 years. Although the clinical examination might implicate some risks for the subjects, the ones used in studies I-II were however of low-risk with the subject at the table supported by two examiners. The MRI was chosen to avoid unnecessary radiation and has also been recommended in the investigation of young subjects[101]. The MRI might however induce claustrophobia which might affect the subjects emotionally. All the subjects were able to choose to opt-out at any time, none of the subjects did however do this concomitant with the MRI examinations.

Studies IV-V used extensive data sets from the Gothenburg Hip Arthroscopy Registry with personal data of sensitive nature. It was thereby vital to respect and secure the integrity of all patients. All the patients are informed about the registry and the research when they apply for the arthroscopic treatment and informed consent is obtained when the patient fills out the questionnaires. The patients have no legal obligation to participate in the Gothenburg Hip Arthroscopy Registry and they can choose to with- draw at any time without providing explanation (7 chap. 2§. Swedish code of statues (SFS) 2008:355).

For all studies in this thesis, data retrieval was performed prior to the implementation of the European General Data Protection Regulation (GDPR). Data is however stored and treated according to current laws and regulations. No subject is able to be identified on an individual level. All studies were conducted in agreement with the Helsinki Declaration and ethical approval was granted by the Regional Ethical Review Board in Gothenburg, Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden (ID number: 692-13 for Studies I-III and registration number EPN: 071-12 for Studies IV-V).

4

SUMMARY OF STUDIES AND RESULTS

STUDY I

Differences in cam morphology and hip range of motion between young skiers and soccer players

INTRODUCTION

Factors, such as genetics, ethnicity and high-impact sporting participation during growth spurt, have previously been associated with cam morphology development[24,25,27-30]. However, there are still many questions related to the etiology of cam morphology and why some athletes develop FAIS and others do not. Comparing different nationalities, genders and different groups of athletes could provide further information about the etiology of cam morphology and FAIS.

The aim was to compare the prevalence of cam morphology, pain and range of motion in the hip joint between young male football players and young male and female skiers, and also to investigate who will fulfill the diagnostic criteria for FAIS.

METHOD

Clinical examinations (including the FADIR test and hip ROM of flexion, IR and ER) and MRI were performed. The α-angle was measured on the MRI scans and a value of ≥55° was considered as cam morphology. All the athletes filled out the Back and hip questionnaire. The diagnostic criteria for FAIS were defined as an α-angle of ≥55°, hip IR <25° and/or a positive FADIR test and self-reported hip pain.

RESULTS

This study is under submission, the results will therefore be published in an upcoming article.

CONCLUSION

No difference was found in terms of the prevalence of cam morphology between Icelandic football players and male skiers, while female skiers had a significantly lower prevalence. Male football players had reduced hip IR and ER as compared with both male and female skiers, while the skiers had a higher prevalence of self-reported hip pain and were more prone to fulfill the FAIS-criteria.

STUDY II

Adolescent elite skiers with and without cam morphology did change their hip joint range of motion with 2 years follow-up

INTRODUCTION

Reduced hip-joint ROM, particularly hip flexion and IR in 90° flexion, is thought to be associated with FAIS[2]. However, there is a discrepancy in the literature when it comes to whether patients with cam morphology have reduced hip ROM compared with healthy subjects or with their unaffected hip[104,105]. Moreover, it is unclear how cam morphology affects hip ROM over time with continuous high sporting activity, such as skiing. The aim was to investigate how hip ROM is affected by continued skiing in young elite skiers with and without cam morphology during a period of 2 years.

METHOD

Skiers at the Åre Ski Academy (National Sports High School), Grades 1-2 (n=35), were examined for the presences of cam morphology (α-angle ≥55°) using MRI at baseline, while hip ROM (flexion, IR, FABER test, IR^{sit} and ER) was examined clinically at baseline and after 2 years.

RESULTS

Table 8 summarizes the baseline characteristics of the study population. The follow-up investigations were staged at 24 months. Five skiers were not able to participate or did not attend the MRI examination and four hips had inferior imaging quality, leaving 56 hips in 13 female and 17 male skiers available for the final analysis. The skiers lost to fol- low-up were similar with regard to age, gender, height, weight, BMI (Body Mass Index), prevalence of cam morphology and hip pain.

Table 8. Baseline characteristics for all skiers stratified by cam and no-cam.

	All skiers (n=30)	Cam (n=14)	No-cam (n=16)
Age, years in mean (SD)	17.3 (0.7)	17.3 (0.8)	17.3 (0.6)
Female gender, n (%)	13 (43)	4 (29)	9 (56)
BMI, kg/m² in mean (SD)	22.5 (2.0)	22.6 (1.7)	22.3 (2.3)

Cam morphology was present in 19 hips (34%, 9 right and 10 left) of 14 skiers (47%; 4 females and 10 males). The cam and no-cam group were similar in terms of age, gender and BMI. All the skiers were still at the elite skiing level at the follow-up. Table 9 shows hip ROM in the cam and no-cam group at baseline and the follow-up. Both groups had a significant reduction in hip ROM for IR, IR^{sit} and ER in both hips and an increase in left hip flexion. Figure 15 shows hip ROM changes from baseline to the follow-up, stratified and compared between groups.

A statistically significant difference was shown for IR^{sit}, where the cam group had a greater mean reduction in both hips (mean group difference in right: 3.3° and left: 4.3°; *P*<0.001) and a larger increase in right hip flexion (mean group difference 6.0°; *P*=0.045). No other significant differences were found between the groups.

Table 9. Hip ROM in skiers with and without cam morphology at baseline and the follow-up.

	Cam			No-cam		
	Baseline	**2 years**	***P* value***	**Baseline**	**2 years**	***P* value***
Flexion, R	118 (3)	125 (3)	0.04	122 (2)	122 (2)	n.s
Flexion, L	119 (3)	128 (3)	0.004	122 (2)	126 (2)	0.004
IR, R	28 (2)	14 (3)	<0.001	31 (2)	20 (2)	<0.001
IR, L	29 (3)	21 (4)	0.004	33 (3)	25 (3)	0.02
FABER, R	71 (2)	66 (3)	n.s	65 (1)	56 (1)	<0.001
FABER, L	65 (1)	65 (3)	n.s	62 (3)	61 (2)	n.s
IR^{sit}, R	33 (3)	23 (3)	<0.001	37 (2)	31 (2)	<0.001
IR^{sit}, L	34 (4)	27 (3)	0.02	39 (3)	36 (3)	0.008
ER, R	39 (3)	22 (2)	<0.001	37 (1)	25 (1)	<0.001
ER, L	39 (2)	21 (1)	<0.001	36 (1)	21 (1)	<0.001

Values are presented in degrees as the mean (SD). *Paired t test between baseline and the follow-up. IR, internal rotation in the supine position; IR^{sit}, internal rotation in the sitting position; ER, external rotation; R, right hip; L, left hip.

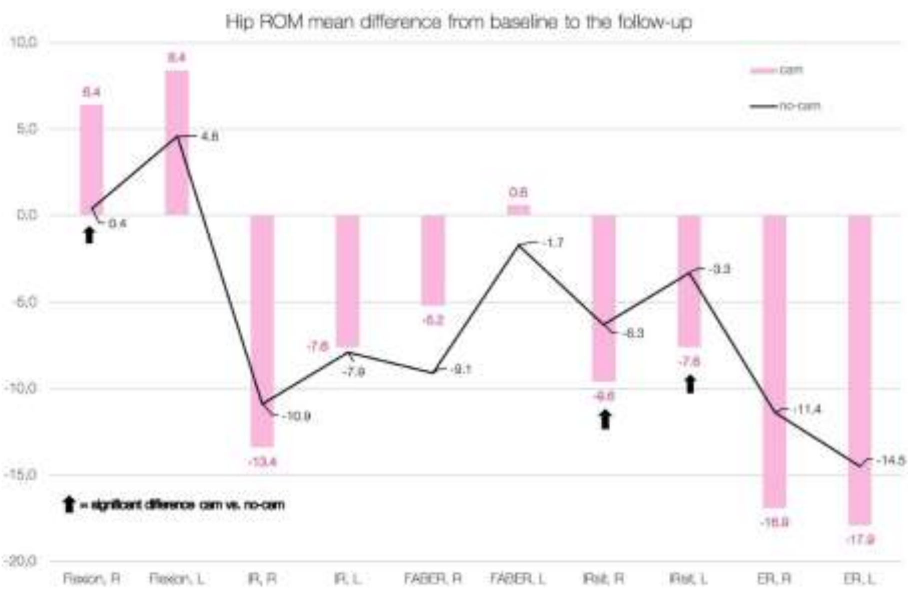


Figure 15. Hip ROM mean difference from baseline to the follow-up between skiers with cam morphology (cam) and skiers without cam morphology (no-cam). Values presented in degrees (°). IR, internal rotation in the supine position; IRsit, internal rotation in the sitting position; ER, external rotation; R, right hip; L, left hip.

CONCLUSION

Adolescent elite skiers had reduced hip internal and external rotation after two years, regardless of the presence of cam morphology. Skiers with cam morphology had a statistically significantly greater reduction in internal rotation in the sitting position.

STUDY III

Hip pain and its correlation with cam morphology in young skiers - A minimum of 5 years follow-up

INTRODUCTION

Conflicting levels of evidence have been reported relating to whether cam morphology is associated with hip pain. Subjects with a higher α-angle have been reported to have a higher prevalence of hip pain and symptoms[50,144]. However, other studies did not find any conclusive association between cam morphology and hip pain[47,145]. It is still unclear which individuals with cam morphology will develop hip pain and symptoms. The aim was to investigate the correlation between cam morphology, hip pain and activity level during a minimum period of five years in young elite skiers.

METHOD

Students in Grades 1-4 at the Åre Ski Academy (National Sports High School) were examined with MRI at baseline (2014) to evaluation cam morphology alongside self-reported hip pain. In 2020, all skiers who participated at baseline were invited to participate at the follow-up, 5 years after the baseline investigation. The skiers completed a shortened version of the baseline questionnaire, including questions regarding present hip pain, activity level and types and frequency of training.

RESULTS

Fifteen skiers (20%) had no up-to-date contact information or could not be reached. The other 60 skiers agreed to participate and completed the follow-up questionnaire (answer rate; 80%) at a mean of 5.7 (SD 0.5) years after baseline examinations. There were no differences between responders and non-responders with regard to baseline age, gender, BMI, presence of cam morphology or hip pain. Table 10 summarizes the characteristics of the included skiers. The mean age at follow-up was 23.6 years and 50% were females. A total of 105 hips in 53 skiers had completed MRI examinations, one hip had poor imaging quality and seven skiers did not attend the MRI examination. All hips were shown with closed femoral growth plates. Cam morphology was present in 39 hips in 25 skiers (47%). Seventeen skiers (28%) reported hip pain at baseline, while 22 skiers (37%) reported the same at follow-up. There was no significant difference between baseline and the follow-up.

Table 10. Characteristics of the 60 subjects included at follow-up.

Age at follow-up, years*	23.6 (1.1)
Female gender	30 (50.0)
Skiing type	
Alpine	45 (75)
Mogul	15 (25)
Cam morphology (α-angle ≥55°)	
Either hip	25 (47)
Right hip only	20 (39)
Left hip only	19 (36)
Bilateral	14 (27)
Hip pain	
Baseline	17 (28)
Follow-up	22 (37)
Self-reported causes of hip pain at follow-up	
Stiffness Surgery	14 (64)
for FAIS	2 (9)
Cam morphology Snapping	1 (5)
hip syndrome Had no	1 (5)
explanation	4 (17)
Values in numbers (%) unless otherwise specified. *Values as the mean (SD).	

Seventy-three percent (n=44) had ended their elite skiing career at a mean of 1.1 (SD 1.4) years after graduation and 48% of these reported that injuries were their reason for finishing (Table 11). Table 11 shows comparisons between skiers still active at elite level and skiers who had finished. A significant difference was found for training days/week at follow-up (still active: 5.3 vs. finished: 3.8 days; $P<0.001$), while no other differences were found.

Table 11. Characteristics and comparisons of skiers still active at elite level and skiers who had finished elite skiing at the follow-up.

	Active at elite competitive skiing level		*P* value*
	Yes (n=16)	No (n=44)	
Age, years	23.6 (1.2)	23.6 (1.1)	n.s**
Female gender, n (%)	6 (38)	24 (55)	n.s
Cam morphology, n (%) hips No cam morphology, n (%) hips	13 (43) 17 (57)	26 (35) 49 (65)	n.s
Hip pain***, n (%) Baseline Follow- up	 5 (31) 8 (50)	 12 (27) 14 (32)	 n.s n.s
Training days per week Baseline Follow-up	 5.9 (0.5) 5.3 (1.0)	 5.8 (0.5) 3.8 (1.6)†	 n.s** <0.001**
Years from graduation to finishing elite skiing		1.1 (1.4)	
Reason for finishing elite skiing, n (%) Hip injury Back injury Knee injury Concussion Motivational Social		 2 (5) 10 (23) 6 (14) 3 (7) 15 (34) 8 (17)	

Values as the mean (SD), unless otherwise specified, *Chi^2 test, **Independent *t* test. ***Values represent skiers reporting hip pain. †Significant difference between baseline and the follow-up using a paired *t* test, *P*<0.001.

HIP PAIN, CAM MORPHOLOGY AND ACTIVITY LEVEL

Self-reported hip pain had a low correlation with the size of the α-angle measured at 1 o'clock in the right hip in skiers with cam morphology, both at baseline (r_s=0.49; *P*=0.03) and at the follow-up (r_s=0.47; *P*=0.04). This correlation was not found for the left hip or for skiers without cam morphology. No other correlations were found between the presence or size of cam morphology at any clock position and hip pain, at either base- line or the follow-up. The mean α-angle ranged between 40.5°±4.5° and 58.5°±4.4°, and 37.7°±3.6° and 49.0°±3.4° across all clock positions in skiers with and without cam morphology respectively.

In the subgroup analysis of skiers, who were pain free at baseline (71 hips in 36 skiers), 11 skiers reported hip pain at the follow-up. Eight of them had bilateral pain, totaling 19 hips with pain. Six of 19 painful hips (32%) were present with cam morphology, whereas 16 of 52 pain-free hips (31%) also had cam morphology. A moderate correlation was found between the size of the α-angle measured at 1 o'clock and developed hip pain in the right hip in skiers with cam morphology (r_s=0.62; *P*=0.03). No other correlations were found between developed hip pain and the presence or size of cam morphology at the follow-up.

CONCLUSION

In young skiers, the presence or size of cam morphology or activity level had no, or only a low, correlation with self-reported hip pain, both at baseline and after 5 years. Cam morphology, in pain-free hips at baseline, did not correlate with the development of hip pain at the follow-up. Almost 75% of the skiers had finished their elite skiing career, with 48% reporting that this was due to different injuries.

STUDY IV

Female athletes have more and longer duration of symptoms prior to arthroscopy for femoroacetabular impingement syndrome

INTRODUCTION

Male gender and certain sports, such as football and ice hockey, have been investigated more frequently with regard to cam morphology. A gender-specific pathogenesis may be possible, as males appear to be more prone to develop cam morphology compared with females[47,66,67]. It may also be that females perform other sports that are not as well studied. Moreover, there is a discrepancy between having cam morphology and fulfilling the diagnosis of FAIS that may require arthroscopic treatment. The aim was to investigate gender differences in the types of sport that are most frequently performed by competitive athletes who have undergone hip arthroscopy for FAIS and also investigate preoperative hip symptoms and function using PROMs.

METHOD

Athletes at competitive level undergoing arthroscopic treatment for FAIS between December 2011 and March 2019 were identified in the Gothenburg Hip Arthroscopy Registry, Sweden. Preoperatively, all athletes completed a set of web-based, self-administered PROMs, including the HSAS (before hip pain onset), iHOT-12 and all six subscales of the HAGOS. At the time of surgery, age, duration of symptoms, sports activity and procedure performed (cam and/or pincer resection) were recorded.

RESULTS

This study is under submission, the results will therefore be published in an upcoming article.

CONCLUSION

In athletes who had had hip arthroscopy for FAIS, football and horseback riding were almost equally frequently performed by females, while football was the sporting activity which was by far the most frequently performed by males. Preoperatively, females had had a longer duration of symptoms and reported a higher degree of symptoms and dysfunction.

STUDY V

Low rate of high-level athletes maintained a return to pre-injury sports two years after arthroscopic treatment for femoroacetabular impingement syndrome

INTRODUCTION

Arthroscopic treatment is increasingly performed in patients with FAIS, with generally good outcomes in both the short and long term[120,123]. The main goal of most athletes undergoing this treatment is to return to sport, and systematic reviews have reported rates of RTS of between 87-92% and 74-88% returning to the same level [60,128,129]. However, several studies state that RTS has been reached when the athlete is able to perform sports (at any or their pre-injury level) on one single occasion and the athlete's ability to continue to perform sport at their pre-injury level, in the long term, can be omitted. The aim was to investigate the rate of competitive athletes who have returned to and are at their pre-injury level of sports two years after arthroscopic treatment for FAIS and to compare the return rate between sports, genders and PROMs.

METHOD

Athletes at a competitive level of sports before the onset of hip symptoms and who had undergone arthroscopic treatment for FAIS between December 2011 and March 2017 were identified in the Gothenburg Hip Arthroscopy Registry, Sweden. The athletes completed a set of web-based, self-administered PROMs, including the HSAS (before onset of hip symptoms and at present), iHOT-12 and the HAGOS six subscales, pre- operatively and 1-2 years postoperatively. Age, duration of symptoms, types of sports activity and procedure performed (cam and/or pincer resection) were recorded at the time of surgery.

RESULTS

A total of 717 athletes met the inclusion criteria and 551 of them (response rate: 77%; 425 males and 126 females) had postoperative follow-up data with a mean follow-up of 23.4 (SD 7.2) months. The median age was 26 (IQR 20-34) years, with no gender difference. A total of 366 athletes (66%) were ≤30 years (median age 22 years) and 185 were >30 years (median age 40 years), with no gender difference. Isolated cam resection, pincer resection and mixed cam/pincer resections were seen in 183 (33%), six (1%) and 362 (66%) athletes respectively.

Responders and non-responders differed in terms of gender (male: 74% vs. 26%; female: 86% vs. 14%; P=0.002), median duration of symptoms (24, IQR 12-60 vs. 24, IQR 12-36 months; P=0.02) and median preoperative score for HAGOS subscale symptoms (43, IQR 29-61 vs. 50, IQR 36-61; P=0.02). No differences were found for age or other preoperative scores.

Females were shown to have a longer duration of symptoms (median 33, IQR 18-60 months vs. 24, IQR 12-48 months; *P*=0.07) and had lower median preoperative scores for all PROMs (symptoms: 39 vs. 46; *P*=0.02, pain: 55 vs. 60; *P*=0.02, ADL: 55 vs. 65; *P*<0.001, sport: 31 vs. 34; *P*=0.02, QoL: 20 vs. 30; *P*<0.001), except for the HAGOS PA subscale and the iHOT-12, compared with males. Postoperatively, only the iHOT-12 differed between genders, where females had lower median scores (63 vs. 74; *P*=0.02). Taken together, all the athletes showed significant improvements in all PROMs from preoperatively to the follow-up (Table 13), with females showing greater improvements in the HAGOS subscales of symptoms (22 vs. 21; *P*=0.04) and ADL (20 vs. 15; *P*=0.04).

*RTS^PRE^*

Almost 25% of all athletes (135 out of 551) were defined as RTS^{pre} at the follow-up; 72% were active in sports at lower levels and 3% did no sports. Figure 17 summarizes the rates of RTS^{pre} and noRTS for the entire group, the three most common sports (in this cohort) and by age groups. The highest rate of RTS^{pre} was seen in athletes ≤30 years (31%) and horseback riders (35%).

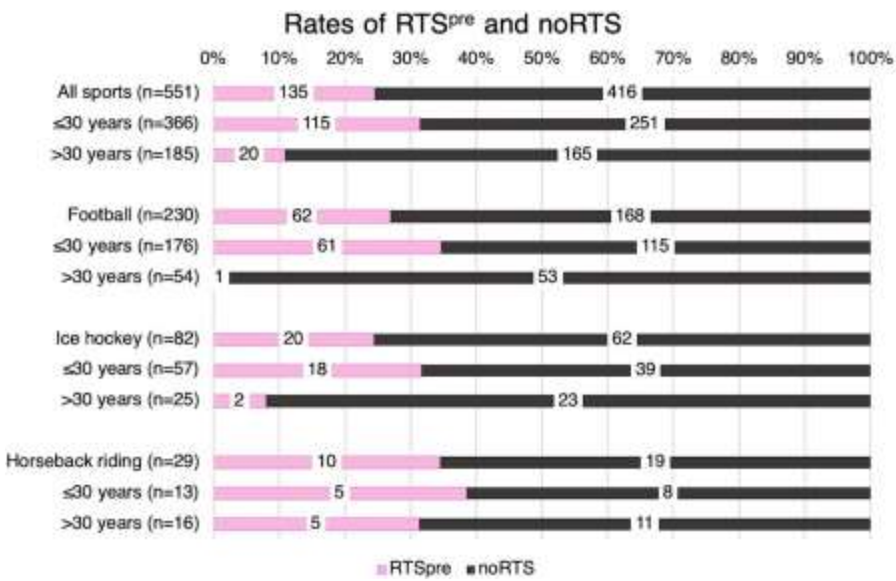


Figure 17. Rate of athletes active at pre-injury level (RTSpre) and not active at pre-injury level (noRTS) for all sports and the most common sports, for the entire group and stratified by age groups. Values in numbers.

RTS^PRE VERSUS noRTS

There were significant differences between RTSpre and noRTS with regard to age (median 22, IQR 19-28 years vs. 28, IQR 21-36 years; $P<0.001$) and duration of symptoms (median 24, IQR 12-48 months vs. 24, IQR 16-60 months; $P<0.001$). Greater improvements from preoperative to the follow-up for iHOT-12 and all HAGOS subscales, except for ADL, and a higher proportion reaching MIC and PASS in all PROMs were also found for the RTSpre group (Table 13; Figure 18). No differences were found for gender: 26% males vs. 19% females were defined as RTSpre.

Table 13. iHOT-12 and HAGOS subscales for RTSpre compared with noRTS preoperatively and two years postoperatively*.

	Preoperative		Postoperative		Change (D)	
	RTSpre	noRTS	RTSpre	noRTS	RTSpre	noRTS
iHOT-12	46 (33-65)	41 (29-52)††	50 (30-80)	80 (60-95)†	29 (11-47)	19 (1-42)†
HAGOS						
Symptom	46 (29-64)	43 (29-57)	82 (71-93)	68 (50-82)†	28 (11-50)	21 (4-39)†
Pain	73 (53-88)	55 (45-78)†	90 (83-100)	78 (55-93)†	18 (0-32)	13 (-5-30)†††
ADL	75 (55-95)	60 (42-80)†	100 (90-100)	85 (60-100)†	15 (0-40)	15 (0-39)
Sport	35 (22-56)	31 (19-50)	88 (69-100)	67 (41-88)†	38 (22-66)	28 (3-50)†
PA	25 (13-50)	13 (0-38)††	88 (75-100)	50 (13-88)†	51 (25-75)	25 (0-63)†
QoL	30 (15-48)	25 (15-40)†††	80 (60-95)	50 (30-80)†	45 (22-65)	25 (5-50)†

Values as the median (IQR, Q^{25}-Q^{75}) RTSpre, active at pre-injury level two years postoperatively, noRTS, not active at pre-injury level two years postoperatively. ADL, Activity of Daily Living, PA, Physical Activities, QoL, Quality of Life. *The Mann-Whitney U test was used to compare RTSpre and noRTS: preoperatively, postoperatively and the change from pre- to the postoperative follow-up respectively. Significant difference between RTSpre and noRTS indicated by †$P<0.001$;††$P=0.003$;†††$P<0.03$.

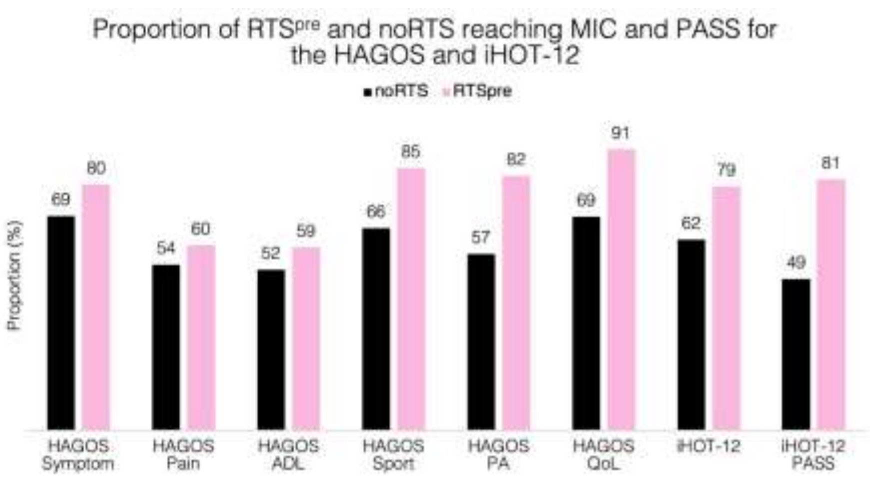


Figure 18. Proportion (%) of RTSpre and noRTS reaching the MIC for the HAGOS six subscales and iHOT-12 and PASS for iHOT-12, two years postoperatively. RTSpre, active at pre-injury sports level, noRTS, not active at pre-injury level; ADL, Activity of Daily Living; PA, Physical Activities; QOL, Quality of Life; MIC, minimal important change; PASS, patient acceptable symptomatic scale.

CONCLUSION

One quarter (25%) of all athletes at competitive level were still active at their pre-injury sports level two years after they had undergone arthroscopic treatment for FAIS. In athletes 30 years or younger, the same was shown in 31%. Those still active were younger and were shown to have higher PROMs pre- and postoperatively, as well as greater clinically relevant improvements from pre- to the postoperative follow-up.

5

DISCUSSION

STUDIES I, II AND III

The main findings in these studies were that cam morphology was equally common in young Icelandic male football players and Swedish male skiers, while female skiers had a lower prevalence. In contrast, 38% and 14% of male and female skiers fulfilled the diagnostic criteria for FAIS respectively, while only 3% of the Icelandic players did the same. Moreover, the football players (Barcelona and Icelandic) had reduced hip IR and ER as compared with the skiers. However, the skiers were shown to reduce their hip IR and ER during the 2-year follow-up study. This was regardless of the presence of cam morphology.

Moreover, no correlations were found between hip pain, activity level, finishing elite skiing and the presence of cam morphology, while inconclusive correlations were found between the size of cam morphology and hip pain in young skiers, during a 5-year follow-up. Almost 75% had finished their elite skiing career and 48% of them had done so due to injuries.

THE PREVALENCE OF CAM MORPHOLOGY

The high prevalence of cam morphology found in male skiers and Icelandic players in Study I is in line with previous studies and supports the theory that high-impact sports participation during the pubertal growth spurt is regarded as a reason for the development of cam morphology[27,28,30]. The present result indicates that there may not be a difference between these two sports types, or between Swedish and Icelandic athletes. In their study, Mosler et al. suggested that there may be ethnic differences in the femoral bony response to athletic load[146]. However, Swedes and Icelanders can be regarded as having similar ethnicity.

Moreover, the gender difference found in Study I with regard to the prevalence of cam morphology also correlates well with previous studies[47,64,66]. Females experience an earlier closure of their growth plate at the proximal femur (e.g. enter the pubertal growth spurt earlier) compared with males[147]. It can be speculated that females' growth plate may already been closed when the demands of training and competing increase at young ages and females may therefore not be as prone to develop cam morphology as males.

HIP ROM AND CAM MORPHOLOGY

In Study I, both the Barcelona and Icelandic football players had a significantly reduced hip IR and ER compared with both male and female skiers. However, Study II showed that skiers reduced their hip IR and ER from baseline to the 2-year follow-up. The results for the football players therefore match the skiers' 2-year result for hip ER but not hip IR. There is a wide variation in the reported values for hip IR and ER between studies, which is probably due to differences in the included populations and the methods used. The American Academy of Orthopaedic Surgery (AAOS) has reported that 'nor- mal' values are 45° for both hip IR and ER[148], while other studies have reported lower values in athletes (IR 11-35° and ER 30-50°)[29,56,149-151]. Despite the fact that the football players had reduced hip IR compared with the skiers in Study I and skiers reduced their hip IR from baseline to the follow-up in Study II, all the results for hip IR match those of previous reports in athletes. However, hip ER in football players in Study I and in skiers at the follow-up in Study II are below the abovementioned reported values, and there may be multiple reasons for these discrepancies.

One explanation of the discrepancy from other studies may be the different positions used while examining hip ER. Studies I and II used a sitting position for ER, while the abovementioned studies used the supine position. Another explanation might relate to whether the pelvis has sufficient stabilization during examination. Aminoff et al. found that both hip IR and ER in the sitting position were affected by the pelvic tilt[152]. This means that, in the case of insufficient stabilization, concomitant movements may occur and thereby result in an overestimation of hip ER[153]. The same testing procedure with an accurate standardized approach and the same two examiners performing all the clinical tests together was used in all the present studies. The differences in hip IR and ER between the skiers and football players in Study I are therefore probably related to the different demands these two sports impose rather than to methodological differences or nationalities. Hip pain was not recorded in either Study I or II in conjunction with the hip ROM examinations, which might also have affected the outcomes.

The reduction in hip IR and ER from baseline to the follow-up in Study II may be explained by the natural change in hip ROM while aging. Studies of young cohorts of general populations (2-17 years) and athletes (15-21 years) have shown a natural re- duction in hip ROM during growth[29,154]. However, the football players in Study I were slightly younger (mean age 17 years) but were still shown to have reduced hip IR and ER compared with skiers (mean age 18 years) in Study I, as well as matching the hip ER to that of the 2-year data in Study II, where the skiers were also 2 years older (mean age 19 years). For this reason, this may not be the only explanation.

Female skiers were shown to have greater hip ROM in every direction compared with all three groups of male athletes in Study I. Females are known to have greater general joint laxity[70,71], which may explain this discrepancy. Another explanation may be that females were shown to have a lower prevalence of cam morphology. However, correlations between hip ROM and cam morphology are inconclusive[104,105]. This was also reflected in Study II, where all the skiers reduced their hip IR and ER from baseline to the 2-year follow-up, regardless of the presence of cam morphology.

In Study II, a statistically significantly larger reduction was found for IR^{sit} (3-4°) in skiers with cam morphology. This did, however, not reach the minimal detectable change of 7°[56] or was not shown for IR in the supine position. These small differences found in Study II between cam and no-cam skiers might be explained by the late fusion of the growth zone of the pelvic bones, where complete union has only occurred by the age of 23 years[155]. It can be speculated that the acetabulum may permit slight movement before complete fusion and cam morphology may therefore not affect the hip ROM. This may also be an explanation of why hip pain and dysfunction are often more prevalent later in life.

Taken together, the reduced hip IR and ER found in football players in Study I and the reduction over time in skiers in Study II may likely be explained by early sporting participation, with adaptations to the particular sporting activity performed, different training regimens and demands rather than the presence of cam morphology. Reduced ROM in the hip joint (and other joints) might increase the risk of injuries[156,157] and these results therefore need to be highlighted to prevent a further decrease in hip ROM and possible secondary injuries.

PROPORTION FULFILLING THE DIAGNOSTIC CRITERIA OF FAIS

One interesting finding in Study I was that, despite the fact that the female skiers were shown to have greater hip IR and a lower prevalence of cam morphology, 50% of females with cam morphology fulfilled the diagnostic criteria for FAIS (i.e. α-angle ≥55°, hip pain and reduced IR (<25°) and/or a positive FADIR test). This means that 14% of all female skiers did fulfill the diagnostic criteria for FAIS. A larger number of male skiers (57% with cam morphology and 38% in total) were found to fulfill the diagnostic criteria for FAIS. In contrast, only one Icelandic football player had the same results. The fact that females appear to have a higher degree of dysfunction and symptoms and a lower level of cam morphology[67,68] is supported in this study and this was also seen in Studies IV and V.

Moreover, football players have previously been shown to run a high risk of FAIS[60,63], which was also supported by Studies IV and V, indicating that the sports type may not be an explanation of this discrepancy between the Icelandic players and male skiers. One reason could, however, be the small proportion of football players reporting hip pain (in total 17%). Why the football players reported less hip pain may have several explanations. One might be that the reduced hip ROM prevents a collision occurring with the acetabular rim in hips with cam morphology. Another could be that the football players were slightly younger and they therefore had an extra year to develop hip pain, or that injured football players may have already left the team or, due to fear of losing their place in the team, they underreport hip pain. Accordingly, this is in contrast to the skiers, who all came from a high school and were therefore not subjected to any such risk of selection.

HIP PAIN, ACTIVITY LEVEL AND CAM MORPHOLOGY

The inconclusive correlation between cam morphology and hip pain found in both Studies I and III is in line with previous conflicting evidence of this correlation[50,54,144,145,156]. Despite the fact that Study I found an association between the presence of cam morphology and hip pain in male skiers, the same was not found in the other groups. Moreover, Study III found no significant correlation between the presence or size of cam morphology and hip pain at any time point, except for the size of the α-angle measured at 1 o'clock in the right hip in those with cam morphology. However, this was not found in the left hip, in those without cam morphology or in the group as a whole, and should be viewed with caution, as only low correlations were shown to exist (baseline: r_s=0.49; follow-up: r_s=0.47). In addition, the development of novel hip pain over 5 years, in pain- free hips at baseline, did not differ between those with and without cam morphology.

Like these results, van Klij et al. found inconclusive correlations in their 5-year follow-up study of young football players[145]. Hip pain was reported not to be associated with radiologically based cam (α-angle ≥60°), large cam (α-angle ≥78°) or visually scored cam, while an association was found for visually scored large cam morphology. Moreover, Mosler et al. investigated a cohort of 438 elite football players and found no correlation between hip injury/pain and cam morphology[54].

In contrast, Khanna et al. found a significantly larger α-angle in hips that developed novel hip pain (44° and 54°) compared with pain-free hips (41° and 51°), during a 4-year follow-up[156]. Similar results were reported by Larson et al., who found that pain was more commonly reported by American football players with cam or mixed morphology, but only larger cam morphology (without specified cut-off values for the α-angle) waspredictive of hip pain[50]. In addition, Guler et al. reported a higher α-angle in hips with pain compared with pain-free hips (55.9° vs. 52.7°)[144]. Based on the theory that cam morphology might lead to degeneration of intra-articular structures causing associated hip pain and dysfunction[119,120], one interpretation of these results could be that a larger cam morphology might imply a higher risk of becoming symptomatic and larger cam morphology might also become symptomatic at an earlier stage compared with smaller ones.

The absence of, or low, correlations between hip pain and the presence and size of cam morphology could be explained by the young age of this cohort. The mean age in Study III at the follow-up was 24 years, while, in the studies by Khanna et al. and Guler et al., the mean age was 30 and 34 years respectively[144,156]. Cam morphology has been suggested to develop during growth spurt, around 12-14 years[27,29,36,44], the duration of cam morphology which was present in Study III might therefore have been too short. In addition, although 47% of the skiers were shown to have cam morphology in Study III, the mean α-angle at each clock position was regarded as fairly low (ranged from 41° to 59°) and, with larger mean α-angles, a greater correlation could perhaps have been found.

Another explanation may be attributed to the fact that almost 75% of the skiers were no longer at elite level. The skiers who had finished their skiing career were reported to have significantly fewer days/week of training (overall) at the follow-up compared with baseline (3.8 vs. 5.8 days), with an additional lower frequency of skiing. The load placed on their hips could therefore become lower, which might affect the risk of hip pain. However, no correlation was found between cam morphology and hip pain in those skiers who were still active at elite level, despite significantly more training days/week (5.3 days). Moreover, both the studies by Khanna et al. and Guler et al. which found these correlations included cohorts from the general population[144,156], indicating that sporting participation may not be the only reason why a person with cam morphology develops hip pain. It still appears unclear why some athletes with cam morphology function at elite level for years, without secondary hip-joint injuries or pain, while others do not.

FINISHING ELITE SKIING AT A YOUNG AGE

Another important finding in Study III is related to the high percentage (48%) of young skiers who had finished their elite careers due to various injuries fairly soon after graduation (mean 1.1 years). Comparing these results with those from other National Sports High Schools is difficult due to the lack of other similar studies. A high incidence of in- juries among athletes at these types of school/academy has been reported (1.7-18.0 injuries/1,000 hours of athletic exposure) of which 10-49% are severe (i.e. time loss from training of 1 months or more)[78-80,84-86]. In an interview study by von Rosen et al., injured adolescent elite athletes questioned the reasons for continuing with elite sports and also whether elite sports were actually appropriate for them[158]. Moreover, a feeling of loneliness when all their friends were training was also highlighted. This suggests that an injury not only affects training and the ability to improve but also affects the psychosocial state.

STUDIES IV AND V

Studies IV and V found that football and ice hockey were the most frequently performed sports among competitive male athletes undergoing arthroscopic treatment for FAIS. In females, football and horseback riding were almost equally frequent, with dancing in third place. Only 25% of all athletes were defined as RTS^{pre} at a mean of 23 months postoperatively. The highest rate of RTS^{pre} were found in athletes aged ≤30 years (31%), while athletes aged >30 years had a significantly lower rate of RTS^{pre} (11%). In contrast, despite the fact that the majority of equestrians were >30 years, they had the highest rate of RTS^{pre} (35%) of the three sports types analyzed (football, ice hockey and horseback riding).

Moreover, female athletes did not differ from males with regard to RTS^{pre}, despite the fact that they were shown to have a longer duration of symptoms and a higher degree of self-reported hip symptoms and dysfunction. When comparing RTS^{pre} with noRTS, the group of RTS^{pre} was shown to have better PROMs pre- and postoperatively, as well as with greater improvements from pre- to the postoperative follow-up.

SPORTS TYPES

The fact that football (in both genders) and ice hockey (in males) were frequently performed in this cohort is not a startling result. These two sports are the top four most common sports in Sweden[159]. In addition, these two sports dominate in studies of cam morphology[35,37,42,44,46,51,54,56,57,63] and studies of RTS after arthroscopic treatment for FAIS[60]. In contrast, horseback riding is a sport that has rarely been mentioned in studies of cam morphology or FAIS, which makes the results of this thesis somewhat surprising and also limits comparisons. Horseback riding is the third most common sport performed by females at competitive level in Sweden and the ninth in both genders[159], which may help to explain this interesting result.

It is therefore speculative that the hips, alongside the spine, absorb a large amount of the landing forces after a jump in a FAIS-exposed position of hip flexion. However, not all horseback riding includes jumping maneuvers (e.g. dressage), which may indicate that the positioning on horseback or in the saddle may be an independent risk factor for developing cam morphology and FAIS in equestrians. The saddle position often includes a slightly anterior-tilted pelvis with the hips in flexion and ER and pressures the hips into IR. Moreover, both the two-point position (seen in jumping) and the “martini glass” position seen in jockeys put the hips into a flexed, internally rotated position with axial loads. The two latter positions are therefore similar to that of the “butterfly” technique used by ice-hockey goalies, who have been shown to have a high prevalence of cam morphology and FAIS[51]. These positions of the hip joint are suggested to be at-risk positions, with a high risk of developing cam morphology and an impingement[62,161].

The fact that dancing was the third most common sports type performed by females in Study IV is an interesting finding as well. Although this result is supported by previous theories that supraphysiological hip ROMs may cause impingement and excessive stress on intra-articular structures, previous studies have reported a fairly low prevalence of cam morphology among dancers (3-18%)[53,58,59]. The discrepancy compared with the findings in Study IV indicate that those “few” dancers with cam morphology appear to run a high risk of developing FAIS and may potentially require treatment.

RETURN TO PRE-INJURY SPORTS LEVEL

The fairly low proportion of competitive athletes (25% of all and 31% of athletes ≤30 years) that was defined as RTS^{pre} in Study V is unfortunate. However, the results are comparable with those in recent studies[130-132]. Wörner et al. and Tjissen et al. investigated the return rate after arthroscopic treatment for FAIS and reported rates of RTS^{pre} of 21% and 19% respectively[130,131]. Moreover, Ishöi et al. reported that 57% of athletes were regarded as RTS^{pre}, but only 30% of these (17% of the whole study population) were able to return to their optimal performance level[132].

On the other hand, previous reports from systematic reviews have shown RTS of 87- 92% and RTS^{pre} of 74-88% [60,128,129]. The main cause of the disparity in relation to the results in Study V is probably the definition of RTS that is used, how it is measured and the time point of follow-up. Several studies have follow-up periods that span several years[60]. However, these studies often assess a successful RTS or RTS^{pre} by if the athlete reach the RTS goal at some time point during the follow-up period.

Two studies defined a successful RTS^{pre} being reached when the athlete was playing in a single season game after the arthroscopic treatment for FAIS, giving rates of RTS^{pre} of 87% and 95% respectively[162,163]. However, this definition means that the athletes are able to play one game and their ability for prolonged performance is unknown. These two studies also reported career length after treatment with a mean of 3.6 (SD 2.9) and 3.2 (SD 2.1) seasons played respectively[162,163], which gives a certain indication of their lasting ability to play. Similar results were also found in the study by Christian et al.[164]. The results of Study V, which aimed to investigate the rate of athletes who were active at their pre-injury level at two years postoperatively, may therefore not be as startling.

AGE

Age is a factor that needs to be taken into consideration when RTS and RTS^{pre} are analyzed. This was also highlighted in Study V where the group of younger athletes (≤30 years) had significantly higher rates of RTS^{pre} compared with athletes aged >30 years. However, the results in this study were inconclusive, as the equestrians were older but still had the highest rate of RTS^{pre}. Moreover, in Study IV the mean age was shown to have a wide variation between different sports types. In team sports such as football, ice hockey and floorball, the athletes' mean age ranged between 22-25 years, while in individual sports, such as cycling, running and horseback riding, mean age ranged between 36-45 years. These results appear to match the age of peak competitive performance that has been reported in the different sport types[160,165,166]. It is possible to speculate that, at these ages, the demands are, or have been, at their highest for the athletes and their hips. Moreover, this may also explain the higher rate of RTS^{pre} seen in equestrians in Study V, as they may have been in the middle of their elite careers.

Another speculative thought is whether minor/moderate variations in cam morphology have the same speed of progression to create intra-articular damage, hip pain and dysfunction and ultimately may lead to arthroscopic treatment for FAIS in different sports. Sports that are not specific high-impact sports and do not include elements of pivoting and cutting, such as horseback riding, may have different developmental patterns, from having only the radiological features of cam morphology to all the diagnostic criteria for FAIS, requiring treatment.

PROMS

All the athletes in Study V had improved their self-reported hip function for all PROMs at the follow-up, which indicates a good quality of surgery and rehabilitation. This re- sult also matches previous studies[112,167]. However, when comparing self-reported hip symptoms and function between RTS^{pre} and noRTS, there were significant differences in almost every PROM in favor of RTS^{pre}, both pre- and postoperatively. RTS^{pre} was also shown to have greater improvements to follow-up, with a higher proportion reaching the MIC in every PROM. In addition, RTS^{pre} had a significantly shorter duration of symptoms, compared with noRTS (24, IQR 12-48 months vs. 24, IQR 16-60 months).

These results indicate that athletes reaching RTS^{pre} appear to have better hip function and less pain/symptoms, which could mean that they may be able to attain their pre-injury level of sports to a higher degree. In contrast to the higher degree of dysfunction and symptoms/pain reported by the noRTS athletes, which may limit their opportunities for sports performance or the desired level of sports. Moreover, previous studies have reported an association between symptom duration and RTS or career length, even though the cause is not entirely known[61,120,163]. One reason could be that they may not have been able to train and compete for years, limiting their opportunity to return to elite level, or other life choices affecting their level of sports for a long time period.

The gender differences found in Studies IV and V is something that needs to be highlighted. Females had significantly lower scores in all the HAGOS subscales, except for PA, and the iHOT-12 preoperatively and were shown to have a longer median duration of symptoms, as compared with males. Postoperatively, the iHOT-12 was the only PROM where males had significantly higher scores. The results are in line with previous studies reporting that females appear to have more hip-related symptoms and disability with fewer radiological findings of FAIS[67,69]. The causes of this discrepancy between genders are not well described. One explanation may be the fact that females are known to have greater general joint laxity[70,71] and may therefore reach further in the hip movement, causing an impingement to occur, despite smaller cam morphology. It is also possible to suggest that females may have treatment for FAIS postponed for different reasons. Conflicting clinical and radiological findings (e.g. present with hip pain and clinical findings but "negative" radiology for FAIS) might be one reason for delayed treatment, which may in turn affect the preoperative self-reported symptoms and function negatively. The fact that there were no differences postoperatively suggests that females appear to benefit equally from arthroscopic treatment for FAIS, which is also supported by the rates of RTS^{pre} being similar in both genders in Study V.

GENERAL DISCUSSION

It is commonly claimed that participation in structured training and competitive sports programs from early ages will benefit the athlete in reaching the goal of elite level. Unfortunately, cam morphology, hip pain and dysfunction appear to be an unwanted side-effect. One key topic that needs to be addressed is why some athletes with cam morphology are able to function at a high level of sports for years, while others develop symptoms and dysfunction related to FAIS and ultimately OA. Inconclusive results between hip pain and cam morphology have previously been reported and were also found in Studies I and III. When and why some athletes become symptomatic and others do not is thereby still a puzzle.

The gender differences that appear to be present related to the development of cam morphology, as well as how the diagnosis of FAIS is expressed, are another key topic that needs to be addressed. Some gender differences have previously been reported and are also shown in this thesis. Study I found that, although the prevalence of cam morphology and hip ROM differed between male and female skiers, the proportion that fulfilled the diagnostic criteria for FAIS in those with cam morphology was similar. Additionally, Study IV showed that females had more and a longer duration of symptoms prior to arthroscopic treatment for FAIS. The fact that no gender differences were shown postoperatively, in either the PROM scores or the rates of RTS^{pre}, suggests that females appear to have results after arthroscopic treatment for FAIS similar to those of males. This means that there is some degree of complexity when it comes to the diagnosis and treatment of cam morphology and FAIS.

Although all the athletes who had undergone arthroscopic treatment for FAIS improved in all PROMs, a fairly small proportion reported still being at their pre-injury level of sports two years postoperatively (Study V). One explanation might be the time between the onset of symptoms and surgery and the athletes' intention to return to sport. Those still active at two years had fewer and a shorter duration of symptoms and dysfunction preoperatively, something that is important to bear in mind.

More rapid surgical treatment may therefore be favorable, or with better/more effective non-surgical treatment that may help minimize symptoms/dysfunction and maintain a high level of sports, to avoid or delay surgery without risking further hip damage. However, the best way of treating these patients still needs to be investigated in greater detail.

The purpose of the National Sports High Schools may be called into question with regard to the fact that almost 75% of the skiers had finished their elite career only one year post graduation, of which 48% did so due to injuries (Study III). In addition to previous reports of a high incidence of injuries among students at these high schools, this leads to the question of a missing link in this context.

Is it that these young athletes, even before high school, train to their breaking point to increase their chances of entering these unique schools? When they subsequently are at these schools, they will have a continued high (or higher) training dose combined with other stressors that the transition to high school could entail (e.g. higher study speed and demands, moving to other places and/or their own apartment, meeting new friends and competitors) which may expose them to an even higher risk of injuries. Is this unique to this high school for skiers? Probably not, but studies of this particular subject are lacking. If we are to achieve the goal of these National Sports High Schools to support young athletes to reach senior international level, we need to find ways of preventing these young athletes from being injured and thereby increase their ability to continue their elite careers.

LIMITATIONS

STUDIES I-III

The MRI examinations in Studies I-III only evaluated the presence of cam morphology by using the α-angle and not other hip morphological changes or hip pathology, which may affect hip ROM and hip pain. The studies did not examine hip pain in direct correlation to hip ROM, which may have affected the outcomes in Studies I and II. Moreover, the inclusion criteria selected only a healthy population which may have affected the opportunity to show the correlation between cam morphology, hip ROM and hip pain. In addition, all the athletes had a closed femoral physis and this might have limited possible growth-related spurts affecting the outcomes. On the other hand, this also means that all the athletes were comparable with each other.

The accuracy, standardization and interpretation of both radiological and clinical measurements are always dependent on the examiner, which may be regarded as a limitation in itself. Studies I-III attempted to limit variations of this kind by using standardized protocols and only two radiologists and two examiners: tests for intra- and inter-rater reliability were also performed. Although good levels of inter-rater reliability were demonstrated between the two radiologists who evaluated the skiers' and Icelandic players' MRI scans respectively, this might have affected the outcomes in Study I.

The lack of MRI examinations in the Barcelona players is a limitation in Study I and larger numbers of MRI's from football players might have helped to develop a better understanding of the underlaying causes of the football players reduced hip ROM.

The lack of power analyses in Studies I-III is also a limitation. The size of the sample may therefore be a limitation and larger cohorts might have revealed greater differences. The variability between the skiing disciplines (Alpine and Mogul) may also have biased the outcomes, as all skiing disciplines were combined in the same group, despite having different skiing patterns.

The Back and hip questionnaire used in Studies I and III has not been validated, which is a limitation in itself. Moreover, questions in terms of past history always entail a risk of recall bias. The follow-up in Study III was made by telephone and a possible impact by the caller might be seen as a limitation. However, by performing the follow-up by tele- phone, the risk of non-responders decreased and a higher answer rate was obtained. To reduce the risk of misleading the responder or interpreting answers, the caller was blinded to baseline results and followed the questionnaire precisely.

STUDIES IV AND V

These studies used an estimation by the participants of their sporting activity level, as it was before the onset of symptoms that may be affected by recall bias. However, the prospectively collected data reduced the risk of recall bias, and this was the only evaluation of the past used in these studies.

The HSAS that was used to evaluate the RTS^{pre} has been shown to have good reliability and validity[127,168] and has been used in previous studies of RTS[169,170]. However, this out- come tool could be fairly difficult to use if, for example, the responder performs a type of sports the HSAS does not mention and this could be regarded as a limitation. The HSAS does not specify the dose of loading or other reasons why the activity level is lower.

One strength in both Studies IV and V was the large number of patients that were included. However, no exclusion of athletes was made with regard to their intention to return to their pre-injury sports level or not, which might have been affected the out- come in Study V. The cartilage status of the hips was not included and this could also be regarded as a limitation in Study V. However, there are contradictory results when it comes to whether or not cartilage status influences RTS and/or career length after arthroscopic treatment for FAIS[61,129].

The Gothenburg Hip Arthroscopy Registry only includes patients from two single centers performing hip arthroscopy in Gothenburg, which may increase the risk of selection bias and also reduce the generalizability to other regions, particularly with regard to sports type performed. On the other hand, having few surgeons and similar surgical approaches allows for generalizability in the follow-up analysis of RTS, PROMs and gender which can be regarded as a strength.

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CONCLUSIONS

STUDY I

No difference was found in terms of the prevalence of cam morphology between Icelandic football players and male skiers, while female skiers had a significantly lower prevalence. Male football players had reduced hip IR and ER as compared with both male and female skiers, while the skiers had a higher prevalence of self-reported hip pain and were more prone to fulfill the FAIS-criteria.

STUDY II

Adolescent elite skiers had significantly reduced internal and external rotation in the hip joint after 2 years of continued skiing, regardless of the presence of cam morphology. The presence of cam morphology was statistically significant but not clinically associated with a larger reduction in internal rotation in the sitting position.

STUDY III

Cam morphology or activity level had no, or a low, correlation with self-reported hip pain during a follow-up period of five years in young elite skiers. Almost 75% of the skiers had finished their elite skiing careers, with 48% due to injuries.

STUDY IV

In athletes who had had hip arthroscopy for FAIS, football and horseback riding were almost equally frequently performed by females, while football was the sporting activity which was by far the most frequently performed by males. Preoperatively, females had had a longer duration of symptoms and reported a higher degree of symptoms and dysfunction.

STUDY V

Only 25% of all competitive athletes and 31% of athletes 30 years or younger were still active at their pre-injury sporting level two years after arthroscopic treatment for FAIS. No gender difference was found with regards to RTS^{pre}, while athletes who were still active had better PROM scores pre- and postoperatively, as well as greater improvements from pre- to the postoperative follow-up.

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JOSEFIN ABRAHAMSON

FUTURE PERSPECTIVES

There is currently strong evidence to suggest that heavy loads on the hip joint during growth spurt will lead to the development of cam morphology. Moreover, there is also strong evidence to suggest that cam morphology is a risk factor in the development of hip OA. This thesis reveals that not only pivoting and cutting maneuvers, commonly seen in soccer and ice hockey, appear to be risk factors for developing FAIS. It therefore remains to investigate the type, dose and timing of loads that might drive the development of cam morphology, future symptoms of FAIS and hip OA. Is it possible to avoid these changes by reducing training intensity and thereby the loads on the hips when the athlete is growing?

During the work on this thesis, it has become clearer, with growing evidence, that there is a gender difference in the development of cam morphology and the way this is expressed with regard to the degree of cam morphology, symptoms and dysfunction. Future research should therefore be separated by gender, in order to acquire a better clinical understanding to help with prevention and treatment for each gender.

There are very few publications on alternative treatments other than surgical for FAIS. Despite the solid evidence that surgical and particularly arthroscopic treatment for FAIS will reduce hip pain and improve function, its effect in the long run is not known. Can the surgical correction of cam morphology slow, or stop, the development of OA, or might it even increase the risk of developing OA? Should different groups of patients be treated differently, depending on gender, age, activity level or degree of arthritic changes? There is also a real need for effective non-surgical treatments to be developed.

Future research should also focus on the effectiveness of National Sports High Schools or similar institutions, with regard to their aim of supporting young athletes to become elite senior athletes and reducing the risk and rates of injuries, thereby increasing the chance of success in elite sports.

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APPENDIX

HSAS

Hip Sports Activity Scale - Swedish

Uppskatta din aktivitetsnivå vid olika tidpunkter enligt skalan nedan. Fyll i den siffra som stämmer bäst.

Uppskatta din nuvarande aktivitetsnivå (oavsett om du är opererad eller inte). [ ] (0-8)
Uppskatta din aktivitetsnivå som den var innan du fick symptom från höften. [ ] (0-8)
Uppskatta din aktivitetsnivå som den var i yngre tonåren (10-15 års ålder). [ ] (0-8)

Nästa

8	Tävlingsidrott (nationell och internationell elitnivå) Fotboll, Ishockey, Innebandy, Kampsport, Tennis, Friidrott, Inomhusaktiviteter, Beachvolleyboll
7	Tävlingsidrott (nationell och internationell elitnivå) Alpin skidåkning, Snowboard, Konståkning, Skridsko, Dans Tävlingsidrott (lägre divisioner) Fotboll, Ishockey, Innebandy, Kampsport, Tennis, Friidrott, Inomhusaktiviteter, Beachvolleyboll
6	Tävlingsidrott (nationell och internationell elitnivå) Golf, Cykel, Mountainbike, Simning, Rodd, Längdskidåkning, Ridning Tävlingsidrott (lägre divisioner) Alpin skidåkning, Snowboard, Konståkning, Skridsko, Dans
5	Tävlingsidrott (lägre divisioner) Golf, Cykel, Mountainbike, Simning, Rodd, Längdskidåkning, Ridning Motionsidrott Ishockey, Innebandy, Kampsport, Fotboll, Friidrott, Beachvolleyboll
4	Motionsidrott Tennis, Alpin skidåkning, Snowboard, Inomhusaktiviteter
3	Motionsidrott Jympa/Aerobics, Jogging, Styrketräning av benen, Ridning
2	Motionsidrott Cykel, Mountainbike, Längdskidåkning, skridsko, Golf, Dans, Inlines
1	Motionsidrott Simning, Promenader, Gång
0	Ingen motions- eller tävingsidrott

HAGOS

Frågeformulär om höft- och/eller ljumskproblem

Datum: ______________________ CPR nr: ____________________

Namn: ____

VÄGLEDNING: Detta frågeformulär innehåller frågor om hur din höft och/eller ljumske fungerar. Du skall ange hur din höft och/eller ljumske har fungerat under **den senaste veckan.** Svaren skall hjälpa oss att kunna förstå hur du har det och hur bra du klarar dig i vardagen.

Du skall besvara frågorna genom att markera det alternativ som passar dig bäst. Om en fråga inte gäller dig eller om du inte upplevt besväret under den senaste veckan, så ange det alternativ som passar bäst in och som du känner dig mest nöjd med.

Symptom

Tänk på de **symptom** och besvär du har haft i din höft och /eller ljumske under **den senaste veckan** när du svarar på följande frågor.

S1. Har du malande/obehag i höften och/eller ljumsken?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

S2. Har du hört klickande eller andra ljud från höften och/eller ljumsken?

Aldrig	Sällan	Ibland	Ofta	Hela tiden
☐	☐	☐	☐	☐

S3. Har du problem med att få benen långt ut i sidan?

Inga	Lite	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

S4. Har du problem med att ta steget fullt ut när du går?

Inga	Lite	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

S5. Får du plötsliga stickande/pirrande förnimmelser i höften och/eller ljumsken?

Aldrig	Sällan	Ibland	Ofta	Hela tiden
☐	☐	☐	☐	☐

Stelhet

Följande frågor handlar om **stelhet i höften och/eller ljumsken**. Stelhet medför besvär att komma igång eller ett ökat motstånd när du böjer höften och/eller ljumsken. **Ange i hur stor grad du har upplevt stelhet i höften och/eller ljumsken under den senaste veckan.**

S6. Hur stel är du i din höft och/eller ljumske när du just har vaknat på morgonen?

Inte alls	Lite	Måttligt	Mycket	Extremt
☐	☐	☐	☐	☐

S7. Hur stel är du i din höft och/eller ljumske senare på dagen, efter att du suttit eller legat och vilat dig?

Inte alls	Lite	Måttligt	Mycket	Extremt
☐	☐	☐	☐	☐

Smärtor

P1. Hur ofta har du ont i höften och/eller ljumsken?

Aldrig	Varje månad	Varje vecka	Varje dag	Alltid
☐	☐	☐	☐	☐

P2. Hur ofta har du ont på andra ställen än i höften och/eller ljumsken som du tycker hänger ihop med dina höft- och/eller ljumskproblem?

Aldrig	Varje månad	Varje vecka	Varje dag	Alltid
☐	☐	☐	☐	☐

Följande frågor handlar om hur mycket smärta i höften och/eller ljumsken under **den senaste veckan. Ange graden av höft- och/eller ljumsksmärta du har upplevt i följande situationer**.

P3. Sträcka ut höften helt och hållet

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P4. Böja höften helt och hållet

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P5. Gå upp- eller nedför trappor

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P6. Om natten när du ligger ned (smärtor som försötr din sömn)

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P7. Sitta eller ligga

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

Följande frågor handlar om hur mycket smärta i höften och/eller ljumsken under **den senaste veckan. Ange graden av höft- och/eller ljumsksmärta du har upplevt i följande situationer**.

P8. Stående

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P9. Gå på hårt underlag, på asfalt eller sten

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

P10. Gå på ojämnt underlag

Ingen	Lätt	Måttlig	Svår	Mycket svår
☐	☐	☐	☐	☐

Fysisk funktion, dagliga aktiviteter

Följande frågor handlar om din fysiska funktion. **Ange graden av besvär du har haft i följande situationer under den senaste veckan, på grund av din höft och/eller ljumske.**

A1. Gå uppför trappor

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

A2. Böjd dig ner, tex för att plocka upp något från golvet

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

A3. Kliva i/ur bilden

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

A4. Ligga i sängen (vända dig eller hålla höften i samma läge under lång tid)

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

A5. Utföra tungt hushållsarbete (tvätta golv, dammsuga, flytta tunga lådor eller liknande)

Inga	Lätta	Måttliga	Svåra	Mycket stora
☐	☐	☐	☐	☐

Funktion, sport och fritid

Följande frågor handlar om din fysiska förmåga. Om en fråga inte gäller dig eller om du inte upplevt besväret under den senaste veckan, så ange det alternativ som passar bäst in och som du känner dig mest nöjd med. **Ange vilken grad av besvär du har haft i följande aktiviteter under den senaste veckan, på grund av problem med din höft och /eller ljumske.**

SP1. Sitta på huk

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

SP2. Springa

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

SP3. Vrida/snurra kroppen när du står på benet

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

SP4. Gå på ojämnt underlag

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

SP5. Springa så snabbt du kan

Inga	Lätta	Måttliga	Svåra	Mycket stora
☐	☐	☐	☐	☐

SP6. Föra benet framåt kraftig och/eller i sidan, exempelvis som vid en spark, skridskosteg eller liknande

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

SP7. Plötsliga, explosiva rörelser som involverar snabba fotrörelser, exempelvis accelerationer, uppbromsningar, riktningsförändringar eller liknande

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

SP8. Situationer där benet rör sig helt ut i ytterläge (med ytterläge menas så långt ut från kroppen som möjligt)

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

Delta i fysisk aktivitet

Följande frågor handlar om din förmåga att delta i fysiska aktiviteter. Med fysiska aktiviteter menas idrottsaktiviteter, men även andra aktiviteter, där man blir lätt andfådd. **Ange i vilken grad din förmåga att delta i önskade fysiska aktiviteter har varit påverkade under senaste veckan, på grund av dina problem med din höft och/eller ljumske.**

PA1. Kan du delta i dina önskade fysiska aktiviteter så länge du vill?

Alltid	Ofta	Ibland	Sällan	Aldrig
☐	☐	☐	☐	☐

PA2. Kan du delta i dina önskade fysiska aktiviteter på din normala prestationsnivå?

Alltid	Ofta	Ibland	Sällan	Aldrig
☐	☐	☐	☐	☐

Livskvalitet

Q1. Hur ofta blir du påmind om dina problem med höften och/eller ljumsken?

Aldrig	Varje månad	Varje vecka	Varje dag	Alltid
☐	☐	☐	☐	☐

Q2. Har du ändrat ditt sätt att leva för att undgå att påfresta höften och/eller ljumsken?

Inget alls	Något	Måttligt	I stor utsträckning	Totalt
☐	☐	☐	☐	☐

Q3. Hur stora problem har du generellt med din höft och/eller ljumske?

Inga	Lätta	Måttliga	Stora	Mycket stora
☐	☐	☐	☐	☐

Q4. Påverkar dina problem med höften och/eller ljumsken ditt humör i en negativ riktning?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

Q5. Känner du dig begränsad på grund av problem med din höft och/eller ljumske?

Aldrig	Sällan	Ibland	Ofta	Alltid
☐	☐	☐	☐	☐

Tack för att du har besvarat Alla frågor!

iHOT12

INTERNATIONAL
HIP OUTCOME TOOL

FORMULÄR OM LIVSKVALITÉ HOS UNGA AKTIVA MÄNNISKOR MED HÖFTPROBLEM

Instruktioner

- Nedan följer 12 frågor om de besvär som du kan uppleva i din höft, hur dessa besvär påverkar ditt liv och de känslor du känner som följd av dessa besvär.

- På varje fråga skall du flytta markören till det läge på skalan som du anser bäst överensstämmer med dina besvär.

  - Om du markerar längst ut till vänster betyder det att du känner dig påtagligt begränsad.

PÅTAGLIGT BEGRÄNSAD — INGA PROBLEM ALLS

  - Om du markerar längst ut till höger betyder det att du inte har några problem alls.

PÅTAGLIGT BEGRÄNSAD — INGA PROBLEM ALLS

  - Om markeringen placeras mitt på skalan betyder det att du är måttligt begränsad, eller med andra ord, mitt emellan 'påtagligt begränsad' och 'inga problem alls'. Det är viktigt att du markerar ända ut i kanten av skalan om det är ytterligheten som bäst beskriver din situation.

- Vänligen låt dina svar beskriva den typiska situationen **senaste månaden.**

  - **TIPS** Om du inte utför en aktivitet, föreställ dig hur det skulle kännas i din höft om du var tvungen att utföra aktiviteten.

När du ställt in markören för en fråga i önskat läge, tryck på "Klar med frågan" så att det står "Klar!" i rutan bredvid.

F1. Totalt sett, hur mycket smärta har du i din höft/ljumske?

EXTREM SMÄRTA — **INGEN SMÄRTA ALLS**

Klar med frågan | Ej klar

F2. Hur svårt är det för dig att ta dig ner på och upp från golvet/marken?

EXTREMT SVÅRT — INTE SVÅRT ALLS

Klar med frågan | Ej klar

F3. Hur svårt är det för dig att gå långa distanser?

EXTREMT SVÅRT — INTE SVÅRT ALLS

Klar med frågan | Ej klar

F4. Hur mycket besvär har du av krasningar, upphakningar eller klickande i din höft?

PÅTAGLIGA BESVÄR — INGA BESVÄR ALLS

Klar med frågan | Ej klar

F5. Hur mycket besvär har du av att knuffa, dra, lyfta eller bära tunga föremål?

PÅTAGLIGA BESVÄR — INGA BESVÄR ALLS

Klar med frågan | Ej klar

F6. Hur oroad är du över riktningsförändringar när du idrottar eller motionerar?

EXTREMT OROAD — INTE OROAD ALLS

Klar med frågan | Ej klar

F7. Hur mycket smärta har du i din höft **efter** fysisk aktivitet?

EXTREMT SMÄRTA — INGEN SMÄRTA ALLS

Klar med frågan | Ej klar

F8. Hur oroad är du över att lyfta upp eller bära barn på grund av din höft?

EXTREMT OROAD — INTE OROAD ALLS

Klar med frågan | Ej klar

F9. Hur mycket besvär har du med sexuella aktiviteter på grund av din höft?

PÅTAGLIGA BESVÄR — INGA BESVÄR ALLS

Klar med frågan | Ej klar

F10. Hur mycket tid är du medveten om dina besvär med din höft?

KONSTANT MEDVETEN — **INTE MEDVETEN ALLS**

Klar med frågan | Ej klar

F11. Hur oroad är du över din möjlighet att upprätthålla din önskade fysiska nivå?

EXTREMT OROAD — **INTE OROAD ALLS**

Klar med frågan | Ej klar

F12. Hur distraherande/störande är dina höftproblem?

EXTREMT DISTRAHERANDE/ STÖRANDE — **INTE DISTRAHERANDE/ STÖRANDE ALLS**

Klar med frågan | Ej klar

OBS! Kolla att det står **"Klar!"** på varje fråga innan du klickar på **"Skicka"**-knappen, så slipper du besvara alla frågorna igen.

Skicka